ENGINEERING INSPECTION PRACTICE

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A Complete Guide to the Methods, Gauges and Instruments used in Engineering Production Workshops

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WITH 246 ILLUSTRATIONS

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PREFACE

RECENT years have produced, owing to the rapid development in mass production methods, a corresponding rise in the status of the engineering inspector. As against the old days when the inspector was regarded as an unnecessary interfering nuisance, both he and his department have come to be recognised as an essential factor towards maintaining the high standard now demanded by the engineering industry as a whole.

It is the author's desire that this book shall appeal and be of valued assistance to the man who feels the urge to get out of the rut of routine inspection, or routine viewing, and rise to the status of a qualified inspector. For this reason the work has been planned as a progressive "Course," starting with the first essential principles and leading up to the present-day methods of mechanical testing.

As under present-day conditions, so much of the inspector's work is subject to the requirements of the Government Inspection Departments, such as the A.I.D. and C.I.A., the final chapter is devoted to the various processes, etc., as specified in the Inspection Leaflets. (Airworthiness Handbook, Vol. 2. Inspection Section.) Those subjects dealt with have been selected as being of value to the general engineering inspector as well as those engaged on aero inspection. The work has been mentioned in Chapter XVII, and contains the whole range of leaflets dealing comprehensively with the Air Ministry's requirements. Other sources of valuable information recommended are the British Standards Specifications published by the British Standards Institution, 28, Victoria Street, London, S.W.1, and the D.T.D. Specifications which are obtainable from H.M. Stationery Office, York House, Kingsway, London, W.C.2.

My thanks are due to the various engineering firms who have so kindly contributed by lending photographs and blocks, acknowledgment for which is made in the text. The data given under the B.S. System of limits and fits has been based on, and extracted by permission from, British Standard No. 164, Limits and Fits (War-time Issue). The permission of the Controller of H.M. Stationery Office has been obtained for the reproduction of Tables 7 and 9, and Figure 3 from the National Physical Laboratory publication "Notes on Screw Gauges" and of the information given on limits of accuracy for cylindrical plug and ring and snap gauges supplied by the Director of the National Physical Laboratory.

A. T. KING.

CONTENTS

Chapter I

READING THE WORKING DRAWING

ONE of the primary qualifications necessary in the practice of engineering inspection is the inspector's ability to read any working drawing.

The orthographic or first angle projection method, as explained in this chapter, is the usual standard accepted in this country and should be sufficient to give the reader a sound knowledge of the principles employed in the making of a working drawing, and assist the reading of the more complicated examples to be found in practice.

Line drawing is the draughtsman's method of detailing machinery and components. Each part is drawn, as requirements demand, in elevation, plan, side elevation, and where necessary extended to sectional views. All views are, where possible, projected from the main elevation.

Elevation

This is the view obtained by looking straight at the object.

Side Elevations

These are obtained by looking at the object as if it were turned through 90°, either right or left from elevation.

Plan

This view is obtained by looking directly down upon the object.

In line drawing, the views or projections are always drawn as though the object were being observed from eye level.

Fig. 1 shows a square box drawn in perspective, and this simple subject will clearly illustrate the method of line drawing as compared with perspective. It will be readily understood that the perspective drawing in this instance would be sufficient to give full particulars for making the box, but at present the aim is to show the " method " of line-drawing projection.

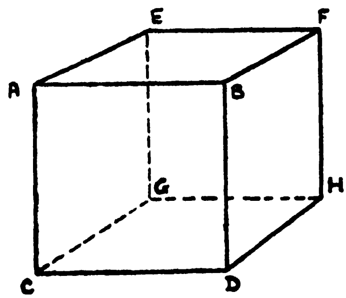


Fig. 1.—Box in perspective

Fig. 2 shows the square box line-drawn, and projected from elevation to three further views. The letters *A* to *H* are added to make clear the relationship of these points on the line drawing, as against the perspective and vice versa. The arrows *X* and *Y* indicate that the right-hand view is projected in the direction of arrow *X*, and the left-hand view in the direction of arrow *Y*. These arrows and also the projection lines do not of course appear in practice.

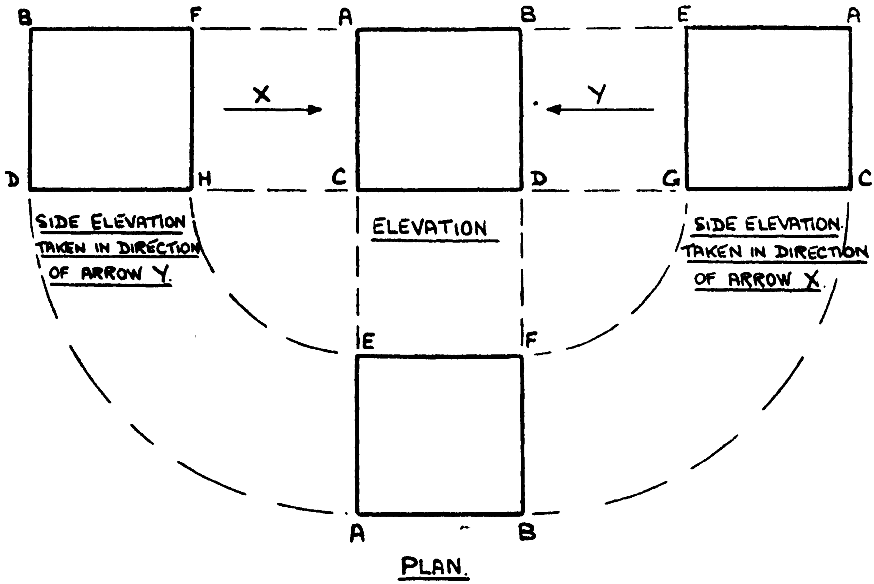


Fig. 2.—LINE DRAWING

A standard rivet is shown in Fig. 3, and it will be seen that the elevation is the only view necessary to give full dimensions for manufacture.

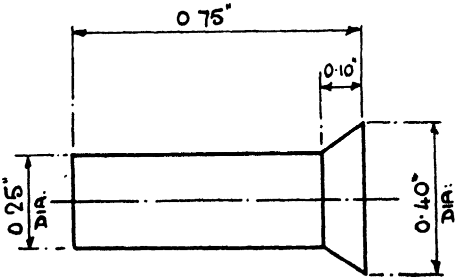


Fig. 3.—STANDARD ¼-IN. RIVET

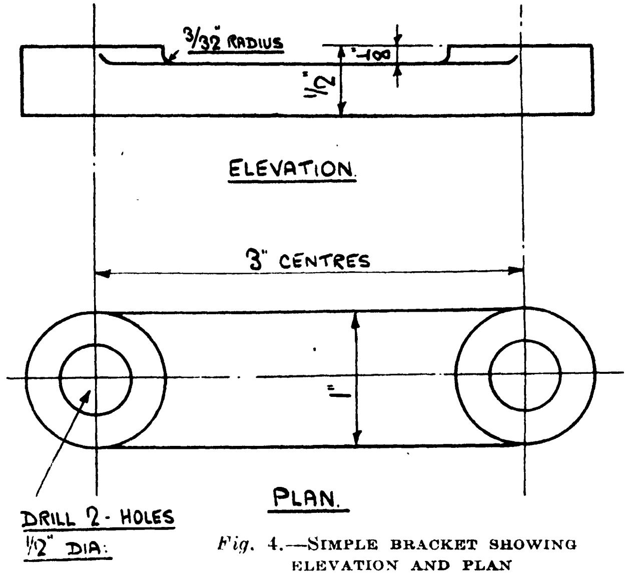


Fig. 4.—SIMPLE BRACKET SHOWING ELEVATION AND PLAN

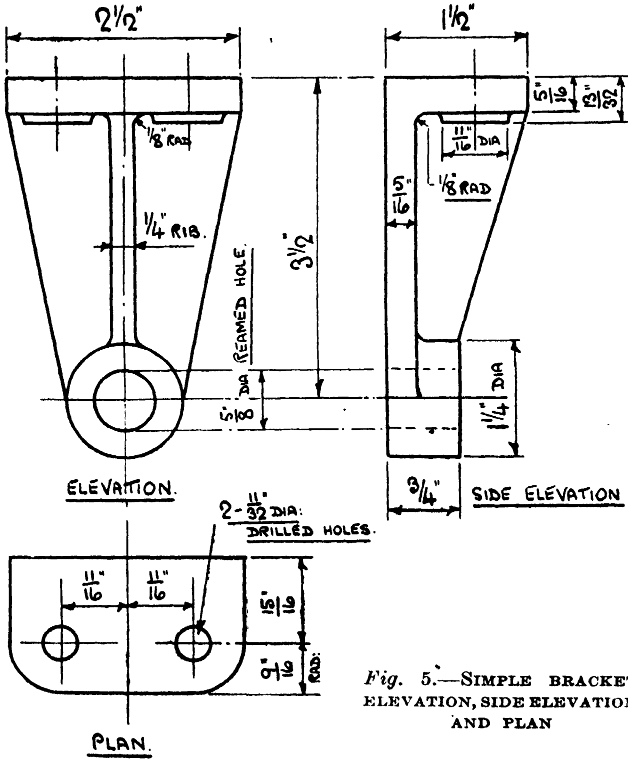


Fig. 5.—SIMPLE BRACKET ELEVATION, SIDE ELEVATION AND PLAN

The draughtsman only plans his drawing to give sufficient views and dimensions for the workman to visualise and make the component.

A simple bracket is shown in Fig. 4, and it will be seen that the elevation and plan are all the necessary views to visualise and manufacture it.

It will be seen that the bracket in Fig. 5 requires three views to give all necessary details.

Another bracket is shown in Fig. 6, in which four views are necessary —the elevation and the three main projections. The dotted line has been introduced in this example to show the contours hidden by the outline. In a more complicated design, it would be essential to portray these by giving sectional projections.

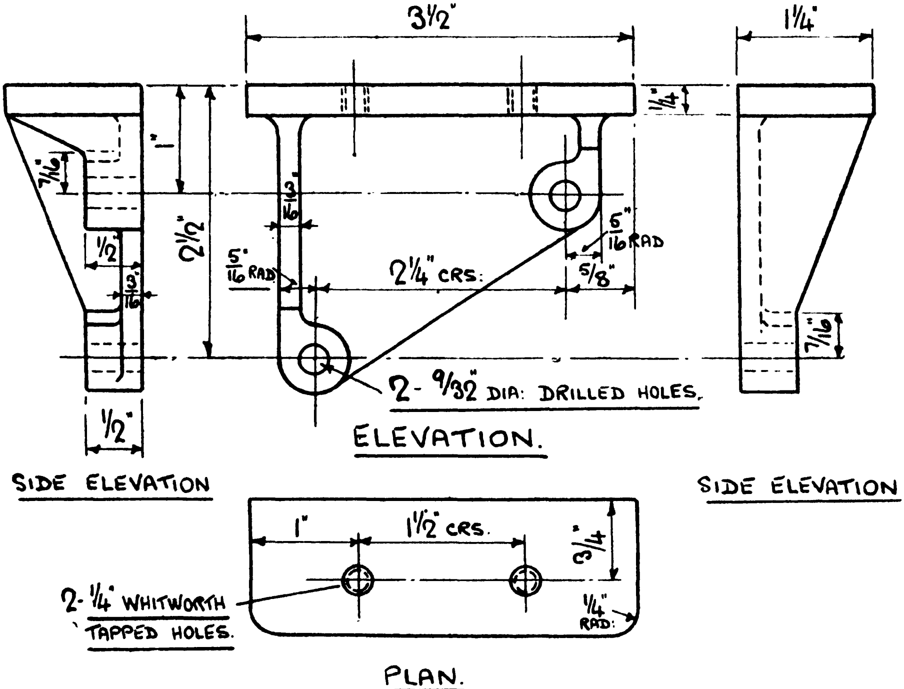


Fig. 6.—BRACKET—ELEVATION AND THREE PROJECTED VIEWS

Fig. 7 shows a simple part-sectional elevation and full-sectional side elevation. A sectional view can be projected through any part of the four main views, and taken through the vertical, horizontal, or any other centre line. The section is usually marked, " SECTION THROUGH A.A.,"

"B.B.," "C.C.," according to the number of sections detailed, and a line marked "A.A.," "B.B.," "C.C.," etc., shown on the view at which the section is taken.

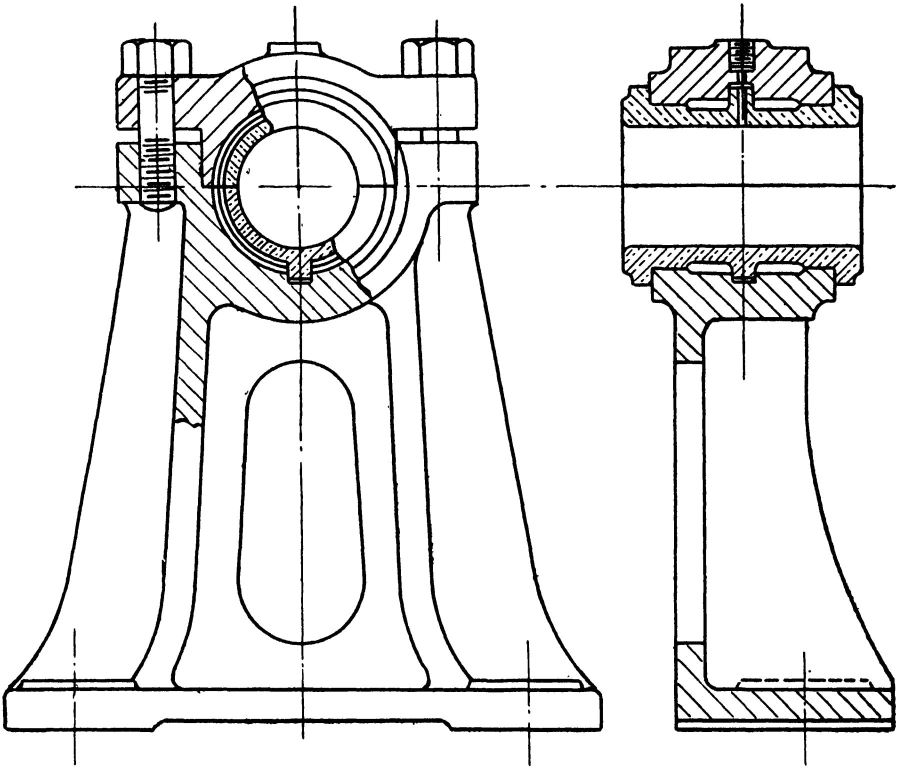


Fig. 7.—PEDESTAL BEARING

In Fig. 8 a more complicated drawing is shown, which should suffice for the requirements of this chapter, as most of the foregoing remarks have been embodied.

Knowledge of the following abbreviations and notes will be found useful :

"*f*" denotes where a machining allowance has been made, and this must be taken into consideration when checking unmachined components.

"*C.L.*," the abbreviation for "centre line."

"*N.T.S.*," the abbreviation for "not to scale." In cases where it is not possible to draw the component full size, a convenient scale is

used, such as half full size, quarter full size, or 1 in. = 1 ft., $1\frac{1}{2}$ in. = 1 ft., 3 in. = 1 ft., etc.

"*P.C.D.*," the abbreviation for pitch circle diameter. Used where holes are spaced on a circular centre line, the pitch circle, and mostly found in the detailing of bolt and rivet holes in flanges.

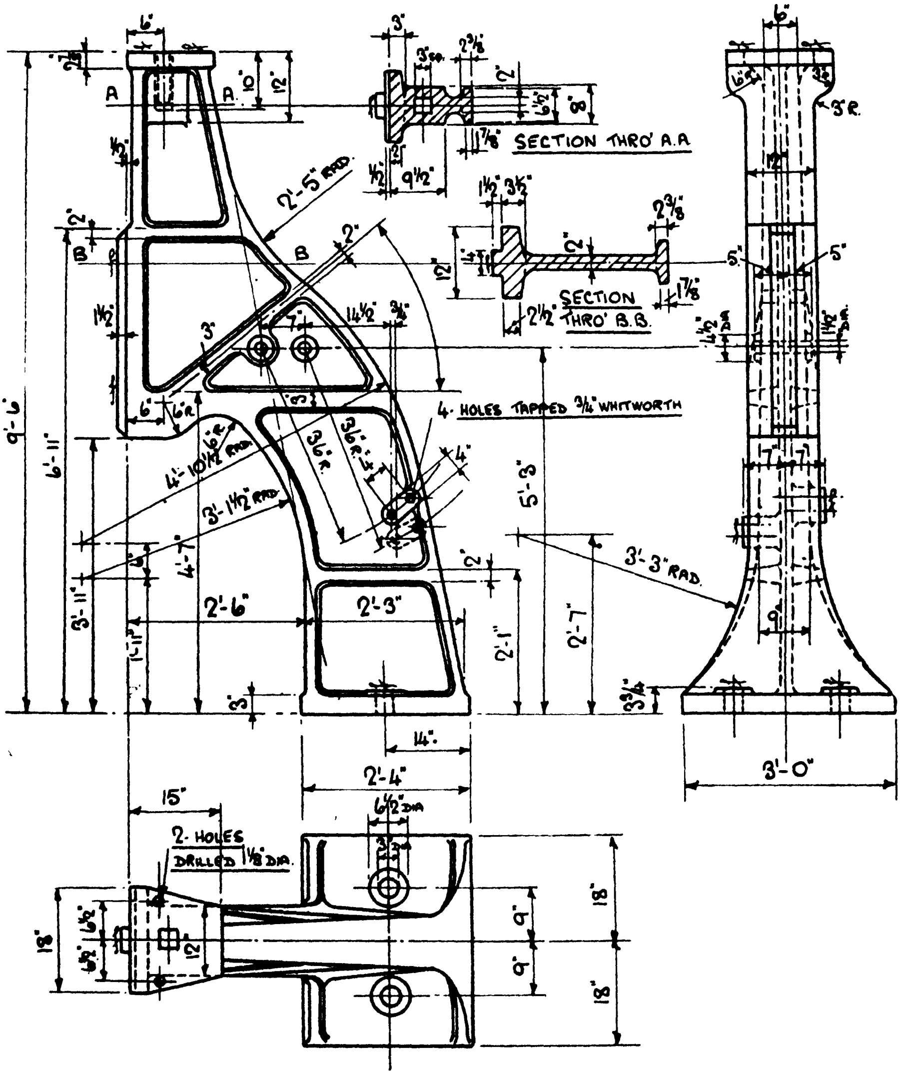


Fig. 8.—CAST-IRON STANDARD FOR POWER HAMMER

"*Ctrs.*," or "*Crs.*," the abbreviation for "centres," denoting the distance between the centre lines of two holes, two shafts, etc.

"*File,*" or "*f.f.*," the abbreviation for "file finish," denoting a particular part to be finished off with a file.

"*G.*," the abbreviation for "grind," or "ground finish," denoting a part of a component to be finally finished off by grinding.

Fig. 9 illustrates the section and hatching lines for various kinds of materials.

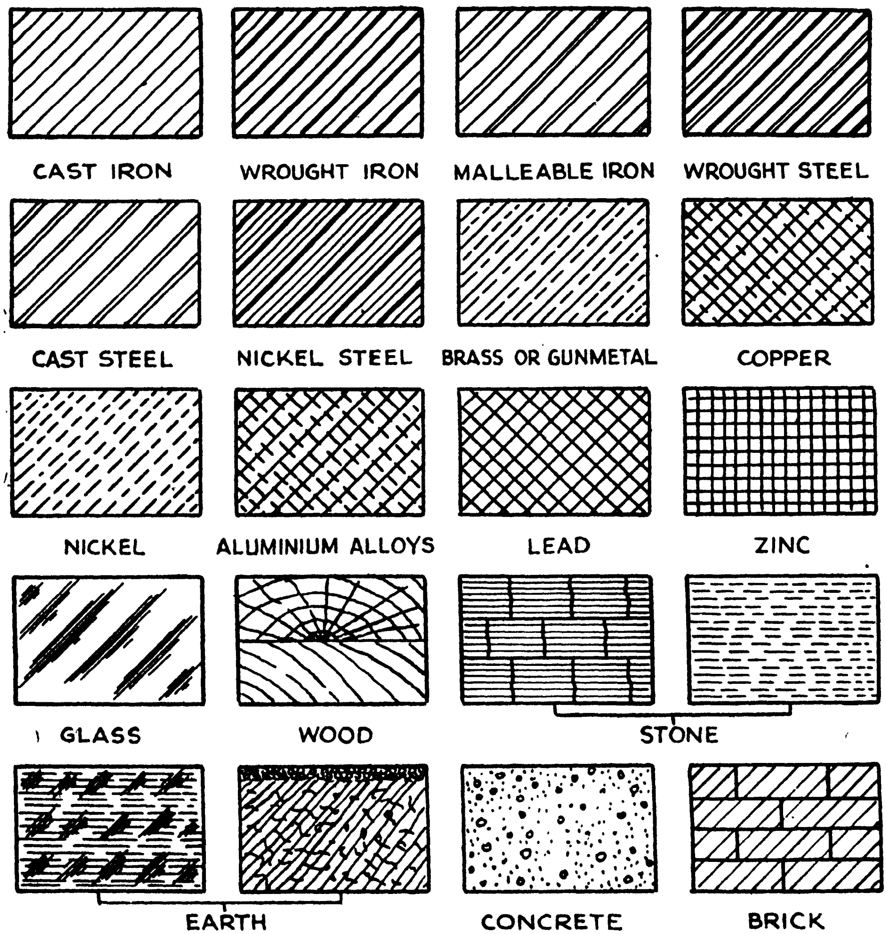


Fig. 9.—Section and hatching lines for various materials

The coloured working drawing is rarely seen in the workshop, but a list of material identification colours is given for reference.

Material	*Colour*
Cast Iron . .	Payne's grey or neutral tint.
Wrought Iron . .	Prussian blue.
Steel . . .	Purple.
Brass or Gunmetal .	Gamboge or Indian red.
Copper . . .	Crimson lake with a little gamboge.
Lead . . .	Indigo.
Glass . . .	Hooker's green.
Wood . . .	Burnt sienna.
Brick . . .	Crimson lake.
Stone . . .	Bistre.
Earth . . .	Sepia.

The method of indicating screw threads is shown in Fig. 10.

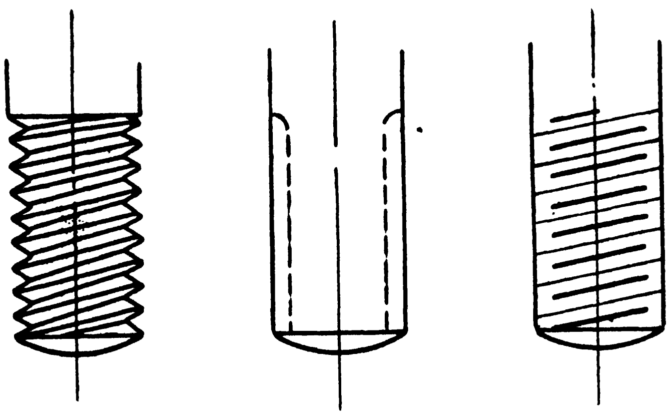


Fig. 10.—Screw threads

Fig. 11 (*A* and *B*) shows the method of indicating a square formation on a circular part of a component by drawing the diagonals of the square.

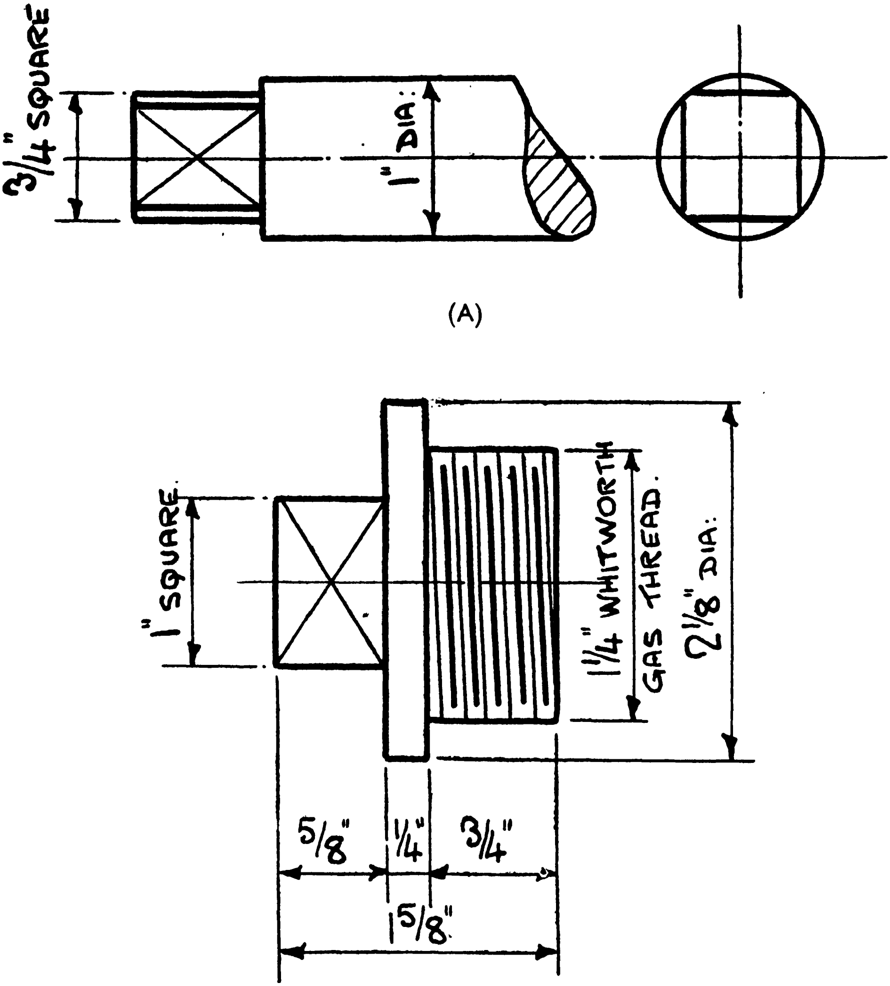


Fig. 11.—INDICATING A SQUARE

Chapter II

LIMITS AND TOLERANCES

IT is humanly impossible for two men to produce identical components. Therefore, limits have to be fixed to decide, in the first place, production requirements, and secondly, satisfactory assembly of the finished product.

Limits can be stated in two ways :

(*a*) 1·750 in. $\pm$ ·005 in. In this case is given a nominal size 1·750 in. and a plus limit of ·005 in., with a minus limit of ·005 in.

(*b*) $1{\cdot}750 \text{ in.} \begin{array}{l} + \cdot 005 \text{ in.} \\ - \cdot 000 \text{ in.} \end{array}$ Here is given a nominal size and plus limit only.

Alternatively, the maximum and minimum sizes can be stated thus :

$$\begin{array}{l} 1{\cdot}755 \text{ in. max.} \\ 1{\cdot}750 \text{ in. min.} \end{array}$$

Tolerance is the difference between the maximum and minimum sizes allowed, or the difference between the high and low limit, thus :

$$1{\cdot}750 \text{ in.} \begin{array}{l} + \cdot 005 \text{ in.} \\ - \cdot 005 \text{ in.} \end{array} = \begin{array}{l} 1{\cdot}755 \text{ in. max.} \\ 1{\cdot}745 \text{ in. min.} \end{array} = \cdot 010 \text{ in. tolerance ;}$$

or, taking the limits : $\begin{array}{l} \cdot 005 \text{ in. high} \\ \cdot 005 \text{ in. low} \end{array}$ by subtraction $=$ ·010 in. tolerance.

Allowance is the clearance between the shaft and hole to allow the various classes of fit.

A careful study of Fig. 12 should give a clear understanding of the terms tolerance and allowance.

The Newall System of Limits is very extensive and widely used. This system is based on the hole size. There are four classes of fit :

(1) *Force fits*, where the hole is expanded by heat to take the shaft. This method is termed "shrinking." Another method of force fit is by forcing the shaft into the hole by hydraulic pressure.

(2) *Driving fits*, where the shaft is driven into the hole by means of a light press, or, in the case of small plugs, with a hammer. A driving fit does not allow the shaft to rotate in the hole.

(3) *Push fit*, where the shaft can be hand pushed into the hole, but will not rotate without danger of seizure.

(4) *Running fits*.—There are three classes :

X for easy fits, engine shafts, etc.

Y for high-speed shafts.

Z for fine-tool work.

Referring to the table of Newall limits, the top two items are the tolerances in standard holes for the previous-mentioned classes of fit. The classes *A* and *B* are used according to the desired accuracy, or can be used to determine the sizes for the operator's and inspector's gauges. Reference to the table shows that the hole size is constant for any class of fit, and the actual fit determined by the fit limits applied to the shaft.

The following examples should make quite clear the procedure for determining limits to the Newall standard :

(1) For operator's and inspector's gauges, assuming a nominal diameter of 1-in. hole size :

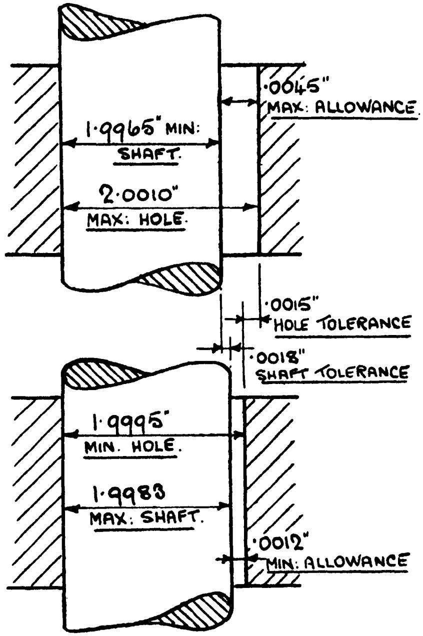


Fig. 12.—DIAGRAM BASED ON 2-IN. DIAMETER NOMINAL HOLE CLASS *B*, WITH SHAFT FOR RUNNING FIT CLASS *X*, ILLUSTRATING TERMS "TOLERANCE" AND "ALLOWANCE"

Operator's gauge, Class *A* : 1 in. $\begin{matrix} + \cdot 00050 \text{ in. NOT GO.} \\ - \cdot 00025 \text{ in. GO.} \end{matrix}$

Inspector's gauge, Class *B* : 1 in. $\begin{matrix} + \cdot 00075 \text{ in. NOT GO.} \\ - \cdot 00050 \text{ in. GO.} \end{matrix}$

The advantage of this system is that, whilst the inspector's gauge does not reject work passed by the operator's gauge, a reasonable degree of accuracy is maintained.

(2) Force fit for 1-in. nominal hole of reasonable accuracy :

Hole (Class *B*) : 1 in. dia. $\begin{matrix} + \cdot 00075 \text{ in.} \\ - \cdot 00050 \text{ in.} \end{matrix}$

Shaft (Class *F*) : 1 in. dia. $\begin{matrix} + \cdot 00200 \text{ in.} \\ + \cdot 00150 \text{ in.} \end{matrix}$

All other classes of fit are determined in the same manner.

STANDARD TABLES OF NEWALL LIMITS

FOR SIZES UP TO 6″

TOLERANCES IN STANDARD HOLES

	Nominal Diameters	Up to and including ½″	Above ½″ up to 1″	Above 1″ up to 2″	Above 2″ up to 3″	Above 3″ up to 4″	Above 4″ up to 5″	Above 5″ up to 6″
Class A	High Limit	+ ·00025	+ ·00050	+ ·00075	+ ·00100	+ ·00100	+ ·00100	+ ·00150
	Low ,,	− ·00025	− ·00025	− ·00025	− ·00050	− ·00050	− ·00050	− ·00050
	Tolerance	·00050	·00075	·00100	·00150	·00150	·00150	·00200
Class B	High Limit	+ ·00050	+ ·00075	+ ·00100	+ ·00125	+ ·00150	+ ·00175	+ ·00200
	Low ,,	− ·00050	− ·00050	− ·00050	− ·00075	·00075	− ·00075	− ·00100
	Tolerance	·00100	·00125	·00150	·00200	·00225	·00250	·00300

ALLOWANCES ON SHAFTS FOR VARIOUS FITS

Force Fits

	Nominal Diameters	Up to and including ½″	Above ½″ up to 1″	Above 1″ up to 2″	Above 2″ up to 3″	Above 3″ up to 4″	Above 4″ up to 5″	Above 5″ up to 6″
Class F	High Limit	+ ·00100	+ ·00200	+ ·00400	+ ·00600	+ ·00800	+ ·01000	+ ·01200
	Low ,,	+ ·00050	+ ·00150	+ ·00300	+ ·00450	+ ·00600	+ ·00800	+ ·01000
	Tolerance	·00050	·00050	·00100	·00150	·00200	·00200	·00200

Driving Fits

	Nominal Diameters	Up to and including ½″	Above ½″ up to 1″	Above 1″ up to 2″	Above 2″ up to 3″	Above 3″ up to 4″	Above 4″ up to 5″	Above 5″ up to 6″
Class D	High Limit	+ ·00050	+ ·00100	+ ·00150	+ ·00250	+ ·00300	+ ·00350	+ ·00400
	Low ,,	+ ·00025	+ ·00075	+ ·00100	+ ·00150	+ ·00200	+ ·00250	+ ·00300
	Tolerance	·00025	·00025	·00050	·00100	·00100	·00100	·00100

Push Fits

	Nominal Diameters	Up to and including ½″	Above ½″ up to 1″	Above 1″ up to 2″	Above 2″ up to 3″	Above 3″ up to 4″	Above 4″ up to 5″	Above 5″ up to 6″
Class P	High Limit	− ·00025	− ·00025	− ·00025	− ·0005	− ·0005	− ·0005	− ·0005
	Low ,,	− ·00075	− ·00075	− ·00075	− ·0010	− ·0010	− ·0010	− ·0010
	Tolerance	·0005	·0005	·0005	·0005	·0005	·0005	·0005

Running Fits (3 Grades)

	Nominal Diameters	Up to and including ½″	Above ½″ up to 1″	Above 1″ up to 2″	Above 2″ up to 3″	Above 3″ up to 4″	Above 4″ up to 5″	Above 5″ up to 6″
Class X	High Limit	− ·00100	− ·00125	− ·00175	− ·00200	− ·00250	− ·00300	− ·00350
	Low ,,	− ·00200	− ·00275	− ·00350	− ·00425	− ·00500	− ·00575	− ·00650
	Tolerance	·00100	·00150	·00175	·00225	·00250	·00275	·00300
Class Y	High Limit	− ·00075	− ·00100	− ·00125	− ·00150	− ·00200	− ·00225	− ·00250
	Low ,,	− ·00125	− ·00200	− ·00250	− ·00300	− ·00350	− ·00400	− ·00450
	Tolerance	·00050	·00100	·00125	·00150	·00150	·00175	− ·00200
Class Z	High Limit	− ·00050	− ·00075	− ·00075	− ·00100	− ·00100	− ·00125	− ·00125
	Low ,,	− ·00075	− ·00125	− ·00150	− ·00200	− ·00225	− ·00250	− ·00275
	Tolerance	·00025	·00050	·00075	·00100	·00125	·00125	·00150

The British Standard System of Limits and Fits

The British Standard Specification applicable to this system is the British Standards Institution's B.S. 164, 1924, *Limits and Fits for Engineering*. The complete Specification is obtainable from the British Standards Institution, 28, Victoria Street, S.W.1, price 2*s*. 3*d*. post free, and should be consulted by those desirous of pursuing the subject farther than can be considered within the limits of this work.

The British Standard system is based on what is known as a "hole basis," which means that the hole size is constant and different "fits" are obtained by varying the size of the shaft.

Limits are specified on the working drawing in two ways: (1) *Unilateral*, or one-way, (2) *Bilateral*, or two-way. The B.S. recommends the unilateral method. When the low limit of the hole is equal to the basic size of the hole, the limit system is said to be unilateral; but when the limits are specified one above and the other below the basic size, it is said to be bilateral.

EXAMPLE:

$$(a)\ \textit{Unilateral}: \begin{array}{l} H.\ 4{\cdot}0016 \text{ in.} \\ L.\ 4{\cdot}0000 \text{ in.} \end{array} \text{ or } 4 \text{ in.} \begin{array}{l} +{\cdot}0016 \\ -{\cdot}0000 \end{array}$$

$$(b)\ \textit{Bilateral}: \begin{array}{l} H.\ 4{\cdot}0008 \text{ in.} \\ L.\ 3{\cdot}9992 \text{ in.} \end{array} \text{ or } 4 \text{ in.} \begin{array}{l} +{\cdot}0008 \\ -{\cdot}0008 \end{array}$$

Before proceeding farther, it should be noticed that when sizes are referred to, they are classified in three ways. The B.S. definitions are:

(1) The *nominal* size of a dimension or part is the size by which it is referred to as a matter of convenience.

(2) The *basic* size of a dimension or part is the size in relation to which all limits of variation are assigned.

(3) The *actual* size of a dimension or part is the measured size of that dimension.

Specification of Holes and Shafts

In the B.S. system, letters are used to specify the classes of holes and shafts. Reference should be made to B.S. 164, 1924, Table 1 for holes, Table 2 for shafts, also to the illustration shown, Fig. 12A "Tolerance Zone Diagram." For holes the letters are, *BUVW* for unilateral holes, *KXYZ* for bilateral holes, and *AGH* for oversize holes. *J* is also specified for non-mating holes and shafts. For shafts the range of letters is *FEDCBKLPMQRST* and *TT*.

The commonest tolerances for good-quality holes are *U* (unilateral) and *X* (bilateral). The British Standard recommends tolerances *B* and *K* only for work of a very precise nature.

In the unilateral specification, Class *B* holes are the most accurate. Class *U* have twice the tolerance of *B*, Class *V* twice that of *U*, and Class *W* twice that of *V* (refer to Tolerance Zone Diagram).

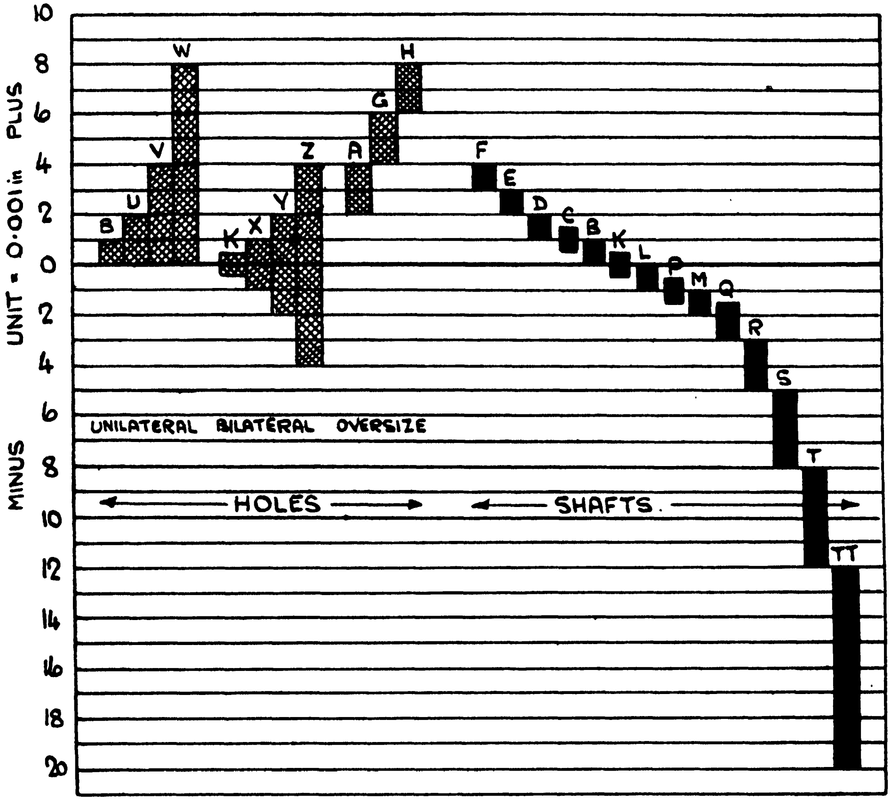


Fig. 12A.—Tolerance zone diagram, B.S.I. 1

In the bilateral specification, Class *K* are the most accurate, the high limit being one-third, and the low limit two-thirds, that of Class *X*. Classes *KXYZ* correspond respectively with *BUVW* in the unilateral specification.

Oversize Holes

The B.S. Table 1 also includes a range *AGH* for oversize holes, in which the low limit of the hole is larger than the nominal size. This range is common to both unilateral and bilateral specifications, and is provided to meet exceptional conditions. A 1-in. nominal-size hole is given a high *L* of + 2·4 ($\frac{10}{1000}$ in.), and a low *L* of + 1·2 ($\frac{10}{1000}$ in.) for Class *A* oversize holes.

Fits

The British Standard definition of " fit " is : " The fit between two mating parts is the relationship existing between them with respect to the amount of play or interference which is present when they are assembled together."

In this system there are three principal classes of fit :

(*a*) *Clearance fit*, where there is a positive allowance between the largest possible shaft and the smallest possible hole.

(*b*) *Interference fit*, where there is a negative allowance (obstruction) between the largest hole and the smallest shaft, the shaft being larger than the hole.

(*c*) *Transition fit*, covering cases between (*a*) and (*b*), i.e. cases in which the limits admit of either clearance or interference fits being obtained.

Designation of Fits

Whilst drawings should always indicate clearly the actual limits to which a component is to be made, it is convenient, for specification purposes, to use symbols. The British Standard recommends a combination of symbols for hole and shaft, thus : *UL, XM*.

For various shafts in a *U* hole, the following can be taken as a guide to the classes of fit :

Designation	*Description of Fit*	*Class of Fit*
UF	Heavy drive	Interference
UE	Light drive	
UD	Heavy keying	Transition
UC	Medium keying	
UB	Light keying	
UK	Push keying	
UL	Slide or easy push	Clearance
UP	Easy slide or close running	
UM	Close running (1)	
UQ	Close running (2)	
UR	Normal running	
US	Slack running	
UT	Extra slack running	
UTT	Coarse clearance	

Bilateral holes *X*, being somewhat smaller than the corresponding unilateral holes, the fits would be :

Designation	*Description of Fit*	*Class of Fit*
XF	Force	Interference
XE	Heavy drive	
XD	Light drive	

Designation	*Description of Fit*	*Class of Fit*
XC .	. Extra light drive	Transition
XB .	. Heavy keying	
XK .	. Medium keying	
XL .	. Light keying	
XP .	. Push keying	
XM .	. Slide or easy push	Clearance
XQ .	. Easy slide or close running	
XR .	. Normal running	
XS .	. Slack running	
XT .	. Extra slack running	
XTT.	. Coarse clearance	

Inspection and Workshop Limit Gauges (Fig. 12 B)

Workshop limit gauges are used during the actual production of the components, whilst the inspection gauges are used to check the finished component. The latter will pass any work which comes within the prescribed limits.

The form of both workshop and inspection gauges is similar, but a definite difference exists between the gauging faces to ensure that all work passed by the workshop gauge will be finally accepted by the inspection gauge. To attain this standard, the tolerance zones for both classes of gauges are disposed in relation to the tolerance zone for the work, as shown in Fig. 12 B.

In the case of inspection gauges, the tolerance zones border on the outside of the tolerance zone for the component, whilst the tolerance zones for the workshop gauges all lie within the tolerance zone of the component. To allow for wear during use, the tolerance zones for workshop plug gauges are separated by a margin from the low limit, and in the case of workshop gap and ring gauges, by a margin from the high limit of those for the component. A smaller margin is often allowed between the tolerance zones for NOT GO workshop gauges and those of the corresponding NOT GO inspection gauges.

TABLE 3.—SIZE MULTIPLIERS

Nominal Sizes In.	*Size Multiplier m*	*Nominal Sizes In.*	*Size Multiplier m*
0– ·29	3	21·0–23·09	22
·3– ·59	4	23·1–25·29	23
·6– ·99	5	25·3–27·59	24
1 0–1·49	6	27·6–29·99	25
1·5–2·09	7		
2·1–2·79	8		

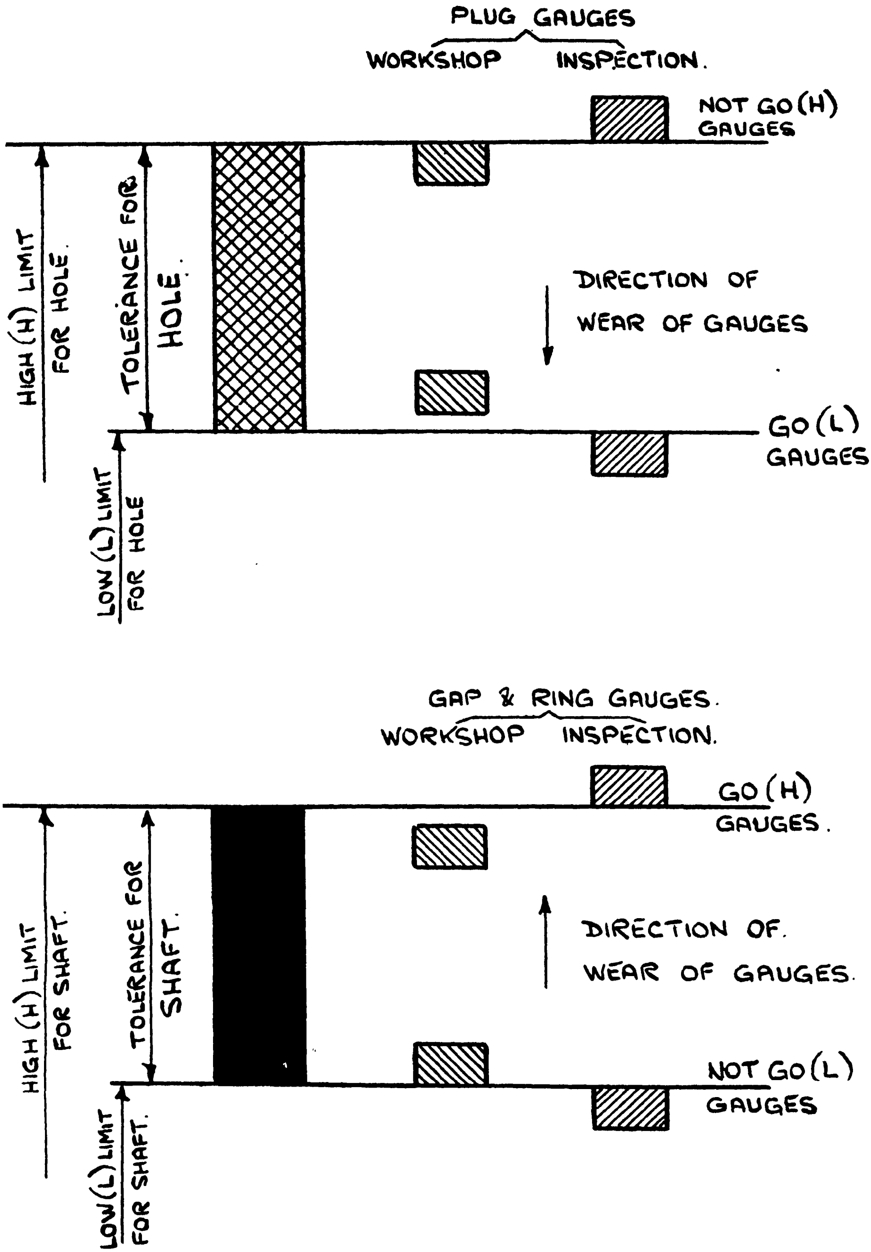


Fig. 12B.—Arrangement of limit gauge tolerances, B.S.I. 2

Construction of Tables

The B.S. Tables 1 and 2 have been calculated from a simple arithmetical relationship which is explained in B.S. 164, 1924. The limits of tolerance are obtained by means of two simple factors consisting of a size multiplier m related to the nominal size of the work, and a range factor r related to the quality of the work. The values for m and r are given in Tables 3, 4 and 5, B.S. 164. Part of Table 3 is shown, but the value of r can be taken for the present purpose from Fig. 12 A, reading the scale in ten-thousandths of an inch. The limits of tolerance for any size and standard of work can be readily calculated by multiplying together the appropriate size multiplier m and the range factor r. The product of these is in thousandths of an inch, and the H and L signs are controlled by the corresponding signs of r.

Examples for Holes

(1) Required, the limits for 1·5-in. B hole:

From Table 3: $m = 7$.
From Fig. 12 A: $r = +1$ for H.

Thus, $H = \dfrac{7 \times 1}{10000} = \cdot0007$ in.

There being no range factor for L, this being obvious, as B holes are unilateral, the limits for the hole are:

H 1·5007 in.
L 1·5000 in.

(2) Required, the limits for ½-in. V hole.

From Table 3: $m = 4$.
From Fig. 12 A: $r = +4$.

Thus, $H = \dfrac{4 \times 4}{10000} = \cdot0016$ in.

There being no range factor for L, the limits for the hole are:

H ·5016 in.
L ·5000 in.

(3) Required, the limits for 2-in. K hole:

From Table 3: $m = 7$.
From Fig. 12 A: $r = +\cdot5$ and $-\cdot5$.

Thus, $H = \dfrac{7 \times \cdot5}{10000} = \cdot00035$ in.

$L = \dfrac{7 \times (-\cdot5)}{10000} = -\cdot00035$ in.

In this case the 1/100,000 figure is dispensed with by subtracting ·00005 from the H limit and adding it to the L limit, thus—

$$H = \cdot 0003 \text{ in.}:$$
$$L = -\cdot 0004 \text{ in.}$$

and the limits for the hole are—

H 2·0003 in.
L 1·9996 in.

and at the same time retaining the tolerance of ·0007 in.

(4) Required, the limits for 1½-in. G hole :

From Table 3 : $m = 7$.
From Fig. 12 A : $r = +4$ and $+6$.

$$\text{Thus, } H = \frac{7 \times 6}{10000} = \cdot 0042 \text{ in.}$$

$$L = \frac{7 \times 4}{10000} = \cdot 0028 \text{ in.}$$

The limits for the hole are :

H 1·5042 in.
L 1·5028 in.

Examples for Shafts

(1) Required, the limits for 1-in. E shaft.

From Table 3 : $m = 6$.
From Fig. 12 A : $r = +2$ and $+3$.

$$\text{Thus, } H = \frac{6 \times 3}{10000} = \cdot 0018 \text{ in.}$$

$$L = \frac{6 \times 2}{10000} = \cdot 0012 \text{ in.}$$

The limits for the shaft are :

H 1·0018 in.
L 1·0012 in.

(2) Required, the limits for 2-in. S shaft :

From Table 3 : $m = 7$.
From Fig. 12 A : $r = -5$ and -8.

$$\text{Thus, } H = \frac{7 \times (-5)}{10000} = -\cdot 0035 \text{ in.}$$

$$L = \frac{7 \times (-8)}{10000} = -\cdot 0056 \text{ in.}$$

The limits on the shaft are :

H 1·9965 in.
L 1·9944 in.

Chapter III

LINEAR AND ANGULAR MEASUREMENT

LINEAR MEASUREMENT

THE measurement of length, width, thickness and diameter, etc., is known when the number is obtained which indicates its magnitude.

A definite unit must be selected, and the number of times the unit is contained in the quantity to be measured gives the numerical value of the quantity.

In order to measure length, there must be a unit and a standard. The unit is a definite distance with which all other distances can be compared. The standard is a bar on which the unit is accurately and permanently marked.

British System

This system is based on the Imperial standard yard, and may be defined as the distance between the centres of two gold plugs, in a particular bronze bar, when the bar is at a temperature of 62° F. The bar is deposited at the Standards Office of the Board of Trade.

The yard is, for convenience, divided into feet and inches. One-third of the Imperial standard yard is one FOOT, and one-twelfth of a foot is one INCH. The inch is further subdivided into equal parts of eight, ten, sixteen, or more. These can be expressed as $\frac{1}{8}$ in. or ·125 in., $\frac{1}{10}$ in. or ·10 in., $\frac{1}{16}$ in. or ·0625 in., etc.

Metric System

This system is based on the standard METRE, as established by French law. The metre is the distance between the two ends of a platinum and iridium bar containing 90 parts platinum and 10 parts iridium. The measure is derived from a quadrant of the earth's meridian, divided into 10,000,000 equal parts, of which the metre is a subdivision. The bar is standard at 0° C.

For convenience, the metre is divided into ten equal parts called

decimetres, the decimetre subdivided into ten equal parts called centimetres ($\frac{1}{100}$ of a metre), and the centimetre into ten equal parts called millimetres ($\frac{1}{1000}$ of a metre).

METRIC MEASURES OF LENGTH

10 millimetres	=	1 centimetre.
10 centimetres	=	1 decimetre.
10 decimetres	=	1 metre.
10 metres	=	1 decametre.
10 decametres	=	1 hectometre.
10 hectometres	=	1 kilometre.
10 kilometres	=	1 myriametre.

CONVERSION OF BRITISH TO METRIC MEASURES OF LENGTH

1 in.	=	2·54 centimetres.
1 ft.	=	30·48 centimetres.
1 yd.	=	·914 metre.

METRIC TO BRITISH

1 millimetre	=	·039 in.
1 centimetre	=	·394 in.
1 metre	=	39·371 in. 3·28 ft. 1·094 yd.

ANGULAR MEASUREMENT

In angular, as in linear, measurement, a suitable unit of measurement is selected. The number of times this unit is contained in any angle is the numerical measure of that angle.

There are two units in general use, the degree and the radian. The degree is determined by taking a circle of any convenient diameter, and dividing the circumference into 360 equal parts. If two consecutive divisions are joined to the centre of the circle, the two lines contain an arc of the length equal to $\frac{1}{360}$ part of the circumference, and the angle between them is the angle of 1°. For accurate measurements, the degree is divided into sixty equal parts called minutes ; and each minute subdivided into sixty equal parts called seconds.

Abbreviations are used for these denominations, and an angular measurement of 65°, 12 mins., 20 secs. would be expressed as $65^\circ\ 12'\ 20''$.

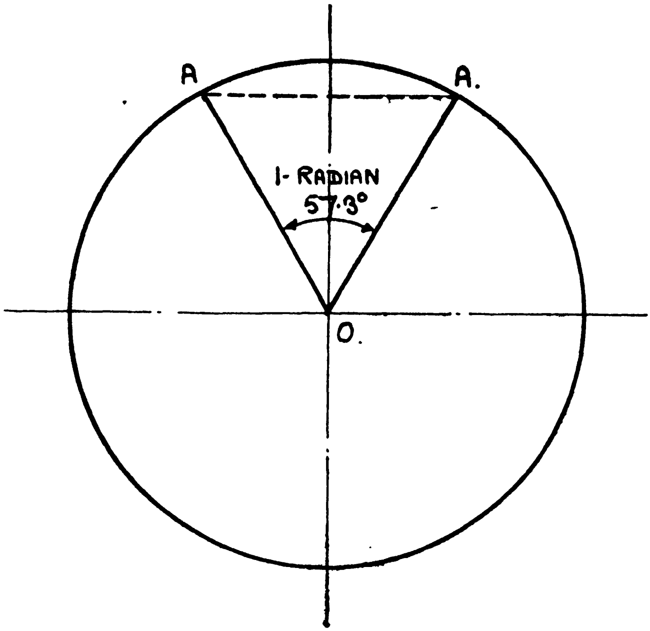


Fig. 13.—THE RADIAN

The French use the number 400 instead of our 360, as they prefer to divide up a right angle into 100°, or, to use their term, "grades."

The Radian (Fig. 13) is obtained by taking a circle of any convenient diameter, and marking off a portion of the circumference equal in length to the radius. Two lines drawn from the extremities of this arc AA to the centre of the circle O will enclose an angle of 1 radian of 57·2958°, or approximately 57·3°.

The angular measurement is expressed by the fraction of a circle, as the length of the sides enclosing the angle has no connection with the magnitude of the angle (see Fig. 14). AB 6″, AC 8″, and the angle enclosed is 45°. It will be seen that, if AB is extended to AD and AC to AE of any length, the angle remains 45°.

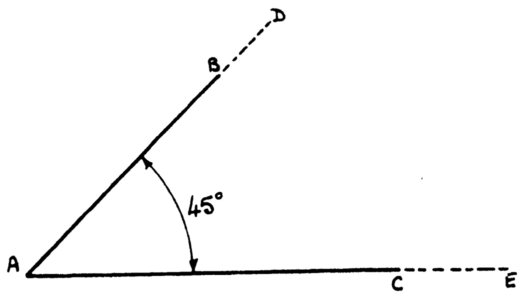


Fig. 14.—THE MAGNITUDE OF AN ANGLE

Angles (Fig. 15)

Starting at a point A due east, and proceeding in the direction of the arrow to point B on the north line, the angle traversed is 90°, or one right angle. Continuing to point C (A to C), the angle traversed is 180°, or a

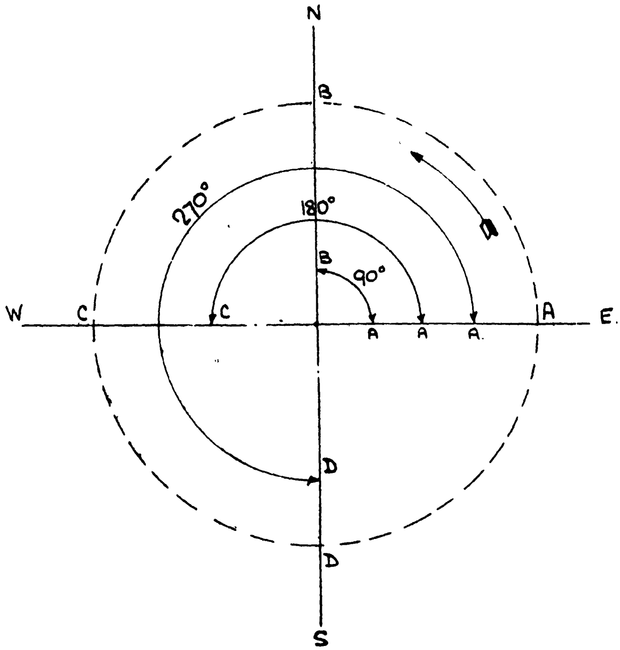


Fig. 15.—ANGLES

straight angle. Continuing farther to D (A to D), the angle traversed is 270°, or three right angles. Completing the circle at A, the whole distance traversed is 360°, or four right angles, sometimes termed a "perigon."

Angles exceeding a right angle but less than two right angles are termed "obtuse" angles (Fig. 16) and those less than a right angle (90°) are "acute" angles (Fig. 17). An angle greater than two and less than four right angles is termed "reflex."

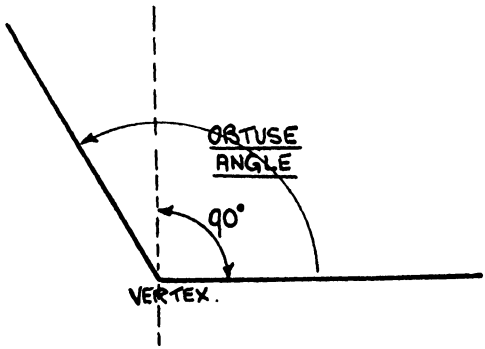


Fig. 16.—AN OBTUSE ANGLE

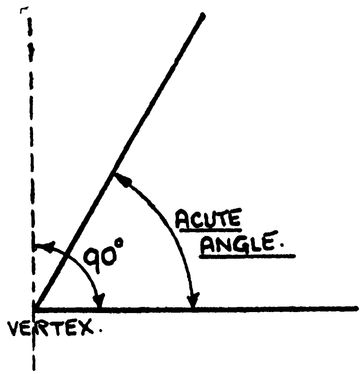


Fig. 17.—AN ACUTE ANGLE

Chapter IV

ARITHMETIC AND MENSURATION REVISION

THE inspector should have, at least, an elementary knowledge of arithmetic and mensuration. It is therefore considered that some simple revision would be useful.

FRACTIONS

Addition of Like Fractions, those having the same denominator, i.e. the lower figure denoting the number of parts into which the whole unit is divided.

Method.—Add together the numerators, i.e. the top figures indicating the number of parts of the whole unit, and place the sum over the common denominator.

Example

$$\tfrac{5}{8} + \tfrac{3}{8} + \tfrac{7}{8} = \frac{15}{8}.\quad \text{Reducing to lowest terms} = 1\tfrac{7}{8}$$

Addition of Unlike Fractions

It is necessary, in such cases, to find the Least Common Multiple (L.C.M.) or Least Common Denominator.

To find the L.C.M.—Arrange all the denominators of the fractions in a line, and cancel any one of these numbers which divides exactly into any of the others. Divide the remainder by a common factor of two or more of these numbers, proceeding as shown :

Find the L.C.M. of 16, 8, 32, 50.

$$\begin{array}{r} 2)\ \cancel{16},\ \cancel{8},\ 32,\ 50 \\ 16\ \ 25 \end{array}$$

$$\text{L.C.M.} = 2 \times 16 \times 25 = 800$$

TO ADD UNLIKE FRACTIONS TOGETHER.—*Method.*—Find the L.C.M., and divide the denominator of each fraction in turn into this number, multiply the result by the numerators of the fractions, and arrange and proceed as for like fractions.

Example.—Add together $\frac{7}{15} + \frac{9}{16} + \frac{9}{10} + \frac{5}{12}$.

$$\text{L.C.M.}\quad \begin{array}{r|llll} 5) & 15, & 16, & 10, & 12 \\ 4) & 3, & 16, & 2, & 12 \\ 3) & 3, & 4, & 2, & 3 \\ 2) & 1, & 4, & 2, & 1 \\ & 1, & 2, & 1, & 1 \end{array}$$

$$\text{L.C.M.} = 5 \times 4 \times 3 \times 2 \times 1 \times 2 \times 1 \times 1$$
$$= 240$$

Therefore, the fractions become—

$$\frac{112 + 135 + 216 + 100}{240} = \frac{563}{240} = 2\tfrac{83}{240}.$$

Addition of Mixed Fractions, i.e. those containing a whole number.

Method.—Add the whole numbers together, proceed as before, and find the value of the sum of the fractions and add together the two results.

Example.—Add together $3\frac{7}{8} + 6\frac{1}{3} + 2\frac{3}{7}$.

$$3 + 6 + 2 + \frac{7}{8} + \frac{1}{3} + \frac{3}{7}$$

Find the L.C.M. $= 8 \times 3 \times 7 = 168$

The example becomes :

$$11 + \frac{147 + 56 + 72}{168}$$

$$11 + \frac{275}{168} = 12\tfrac{107}{168}.$$

Subtraction of Fractions

SUBTRACTION OF LIKE FRACTIONS.—*Method.*—The denominators being alike, subtract the smaller numerator from the greater, and express the fraction in its lowest terms.

Example

$$\frac{15}{32} - \frac{7}{32} = \frac{\overset{1}{\cancel{8}}}{\underset{4}{\cancel{32}}} = \tfrac{1}{4}$$

SUBTRACTION OF UNLIKE FRACTIONS.—*Method.*—Find the L.C.M., and arrange both fractions with this number as denominator. Subtract as for like fractions.

Example

$$\tfrac{13}{20} - \tfrac{1}{3}.$$

L.C.M. $= 60$, and the fractions become :

$$\frac{39}{60} - \frac{20}{60} = \tfrac{19}{60}$$

Subtraction of Mixed Fractions.—*Method.*—Express the fractions as improper fractions, i.e. having a greater numerator than denominator, and proceed as before.

Example

$$8\tfrac{4}{5} - 4\tfrac{2}{3}$$

This becomes $\frac{44}{5} - \frac{14}{3}$.

The L.C.M. $= 15$; and proceeding:

$$\frac{132 - 70}{15} = \frac{62}{15} = 4\tfrac{2}{15}$$

Multiplication of Fractions

Multiplication of Vulgar Fractions.—*Method.*—Multiply the numerators together, and also the denominators, and reduce as before.

Example

$$\frac{3}{5} \times \frac{5}{7} = \frac{\overset{3}{\cancel{15}}}{\underset{7}{\cancel{35}}} = \frac{3}{7}$$

Multiplication of Fractions by Whole Numbers.—*Method.*—Multiply the numerators of the fraction by the whole number, the same denominator being retained.

Example

$$\frac{9}{15} \times \frac{7}{1} = \frac{63}{15} = 4\tfrac{3}{15} = 4\tfrac{1}{5}$$

Multiplication of Mixed Fractions.—*Method.*—Express all mixed numbers as improper fractions, and reduce to their lowest terms by cancellation, where possible. Multiply as for vulgar fractions and reduce again.

Examples

(*a*) $1\tfrac{1}{5} \times 3\tfrac{1}{8} \times 1\tfrac{7}{9} \times \tfrac{3}{20}$

$$= \frac{\overset{2\ 1}{\cancel{6}}}{\underset{1}{\cancel{5}}} \times \frac{\overset{5\ 1}{\cancel{25}}}{\underset{4\ 1}{\cancel{8}}} \times \frac{\overset{4\ 1}{\cancel{16}}}{\underset{3\ 1}{\cancel{9}}} \times \frac{\overset{1}{\cancel{3}}}{\underset{5\ 1}{\cancel{20}}} = 1$$

(*b*) $1\tfrac{1}{2} \times 2\tfrac{2}{3} \times 3\tfrac{3}{4} \times 4\tfrac{4}{5}$

$$= \frac{\overset{1}{\cancel{3}}}{\underset{1}{\cancel{2}}} \times \frac{\overset{4\ 1}{\cancel{8}}}{\underset{1}{\cancel{3}}} \times \frac{\overset{3}{\cancel{15}}}{\underset{1}{\cancel{4}}} \times \frac{24}{\underset{1}{\cancel{5}}} = 72$$

Cancelling can *only* be accomplished in the case of multiplication. Any particular term in the numerator and any one term in the denominator can be divided by a common factor.

Division of Vulgar Fractions

Division by a Whole Number.—*Method.*—Divide the numerator by the whole number.

Example

$$\frac{15}{32} \div 3 = \frac{5}{32}$$

Division of Two Fractions.—*Method.*—Invert the divisor and multiply as for multiplication of fractions.

Example

$$\frac{15}{16} \div \frac{5}{8}$$

$$= \frac{\overset{3}{\cancel{15}}}{\underset{2}{\cancel{16}}} \times \frac{\overset{1}{\cancel{8}}}{\underset{1}{\cancel{5}}} = \frac{3}{2} = 1\tfrac{1}{2}$$

Division of Mixed Numbers.—*Method.*—Convert to improper fractions and proceed as before.

Example

$$9\tfrac{5}{8} \div 3\tfrac{1}{4}$$

$$= \frac{77}{8} \div \frac{13}{4}$$

$$= \frac{77}{\underset{2}{\cancel{8}}} \times \frac{\overset{1}{\cancel{4}}}{13} = \frac{77}{26} = 2\tfrac{25}{26}$$

SQUARES AND SQUARE ROOT

Squares

A number multiplied by itself is termed the "square," or second power of the number. Thus the square, or second power of 4, usually expressed 4^2, is $4 \times 4 = 16$, and again 6^2 is $6 \times 6 = 36$.

A number can be raised to any power of its number in this manner, and the power indicated by the index, the small figure at the top right-hand side, thus : 6^2, 6^3, 6^4, 6^5, etc.

Square Root

The ordinary practical method is as follows. Point the given number into periods, starting with the units place and marking a dot over each second figure. Find the largest number (see example), the square of which is less than 70 ; this is 8. Set this figure to the right of the given number and its square under the first period 70, obtaining the remainder 6. Bring down the second period 56, thereby making the number 656.

Now double the 8 and put 16 into the divisor, and by trial find that 16 will divide into 65 four times. Place 4 as second figure of the answer, and put a 4 with the 16 to make a divisor of 164. Multiply 164 by 4, obtaining 656 which, subtracted from 656, leaves no remainder, and the square root of 7,056 is found to be 84.

$$
\begin{array}{r|l}
 & 7\dot{0}5\dot{6} \;|\; 84 \\
 & 64 \\
\hline
164 & \;\;656 \\
 & \;\;656 \\
\hline
 & \;\;\cdots
\end{array}
$$

Numbers containing decimal places should be dealt with as follows. Always dot the units place, mark off the periods, in this case alternate figures both to the right and left, and proceed as shown in the example.

$$
\begin{array}{r|l}
 & 5\dot{6}\cdot8\dot{5}1\dot{6} \;|\; 7\cdot54 \\
 & 49 \\
\hline
145 & \;7\;85 \\
 & \;7\;25 \\
\hline
1504 & \quad 6016 \\
 & \quad 6016 \\
\hline
 & \quad \cdots\cdot
\end{array}
$$

Square Root of a Fraction

In finding the square root of a fraction, the square root of both numerator and denominator must be found. Where the denominator is not a perfect square, both numerator and denominator should be multiplied by a number which will make the denominator a perfect square (see examples).

(1) $\sqrt{\frac{4}{9}} = \frac{2}{3} = 0\cdot666$

(2) $\sqrt{\frac{5}{8}} = \sqrt{\frac{5}{8}} \times 2 = \sqrt{\frac{10}{16}} = \frac{\sqrt{10}}{4} = \frac{3\cdot1623}{4} = 0\cdot7906$ (nearest)

Addition of Decimals

Method.—Arrange the numbers immediately beneath each other, keeping the decimal points in line, and add together.

Example

$$
\begin{array}{r}
5\cdot9278 \\
18\cdot3754 \\
57\cdot8250 \\
0\cdot3291 \\
\hline
82\cdot4573
\end{array}
$$

Subtraction of Decimals

Method.—Arrange as for addition and subtract.

Example

198·3582 − 54·5908

```
198·3582
 54·5908
143·7674
```

Division of Decimals

Method.—Bring the divisor to a whole number, noting the number of places the decimal point has to be moved in so doing. Move the decimal point the same number of places to the right in the dividend and divide as for long division.

Example

Divide 0·01829 by 7·326.

```
7326)18·290(0·00249
     14 652
      3 6380
      2 9304
        70760
        65934
```

The answer is 0·0025, correct to four places of decimals.

Multiplication of Decimals

Method.—Proceed as for ordinary multiplication, ignoring the decimal point until the product is obtained. Then, adding the number of decimal places together both in the multiplier and multiplicand, starting from the extreme right of the product, count this number of figures off and insert the decimal point.

Example

11·416 × 3·16

```
  11416
    316
  68496
 11416
34248
3607456
```

Inserting the decimal point, the answer is 36·07456.

MENSURATION REVISION

Square.—Area = Length × Breadth.

DIAGONAL OF SQUARE = Side × $\sqrt{2}$.

RECTANGLE.—Area = Length × Breadth.

PARALLELOGRAM.—Area = Base × Perpendicular Height.

TRIANGLE.—Area = $\frac{1}{2}$ (Base × Perpendicular Height) or

$$\frac{\text{Base} \times \text{Perpendicular Height}}{2}$$

Circle.—Area = πr^2 or $\frac{\pi D^2}{4}$ or $\cdot 7854\ D^2$

$$\text{Circumference} = D \times \pi \text{ or } \frac{D}{0{\cdot}3183}$$

$$\text{Diameter} = \frac{\text{Circumference}}{\pi} \text{ or Circumference} \times 0{\cdot}3183.$$

ANNULUS OF CIRCLE.—Area = $(D^2 - d^2) \times 0{\cdot}7854$,
or $\pi(R^2 - r^2)$.

SECTOR OF CIRCLE.—Area = $\frac{N}{360} \pi R^2$.

SEGMENT OF CIRCLE.—Area = (Area of Sector − Area of Triangle).

SPHERE.—Surface = $4\pi R^2$.

Symbols used in connection with the Foregoing

D = outside diameter. d = inside diameter.

R = outside radius. r = inside radius.

N = number of degrees contained in angle of sector.

$\pi = 3{\cdot}1416$ or $\frac{22}{7}$ (approximate).

Unit of Area is the area of a square upon a line of unit length. The British unit of length is the yard, and therefore the unit of area is the square yard. This unit is subdivided into the square foot or square inch as is most convenient.

Greek Letters used as Symbols

Capital	*Small*	*Name*
Α	α	Alpha
Β	β	Beta
Γ	γ	Gamma
Δ	δ	Delta
Ε	ε	Epsīlon
Ζ	ζ	Zēta

Capital	*Small*	*Name*
Η	η	Ēta
Θ	θ ϑ	Thēta
Ι	ι	Iōta
Κ	κ	Kappa
Λ	λ	Lambda
Μ	μ	Mu
Ν	ν	Nu
Ξ	ξ	Xi
Ο	ο	Omīcron
Π	π	Pi
Ρ	ρ	Rho
Σ	σ ς	Sigma
Τ	τ	Tau
Υ	υ	Upsīlon
Φ	φ	Phi
Χ	χ	Chi
Ψ	ψ	Psi
Ω	ω	Omega

Chapter V

TRIGONOMETRY

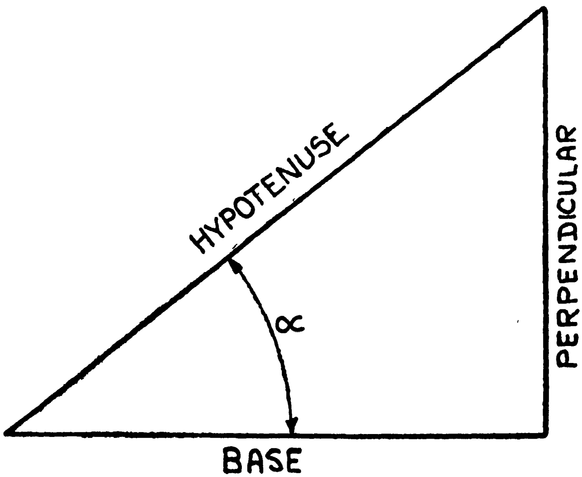
(SOLUTION OF RIGHT-ANGLE TRIANGLES)

THE **Tangent** of an angle is the ratio of the perpendicular height to the base of a right-angle triangle.

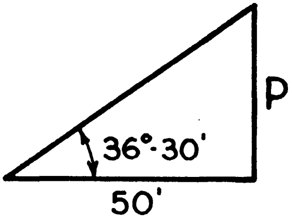
Thus : $\frac{\text{Perp.}}{\text{Base}}$ = tangent, usually written tan.

Example.—Given perp. = 37 ft., base = 50 ft.

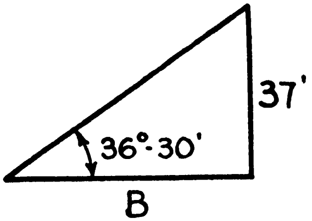
$\frac{37}{50} = 0{\cdot}740$. This ratio is called the tan. Referring to the Tangent table (see end of book), tan 0·740 = 36°-30′. Any right-angle triangle in which the length of perpendicular divided by the length of base gives



a ratio of 0·740, will have a base angle of 36°-30′. To check the foregoing and illustrate the method of finding the length of either perpendicular or base, proceed thus :



$P = \tan 36°\text{-}30' \times 50'.$
(Ref. Table, $\tan 36°\text{-}30' = 0{\cdot}7400$)
$0{\cdot}7400 \times 50.$
37 ft.



$$B = \frac{37}{\tan 36°\text{-}30'} = \frac{37}{0{\cdot}7400} = 50 \text{ ft.}$$

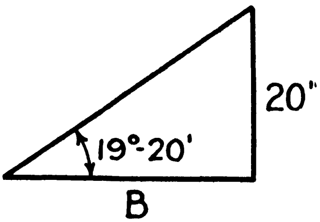
The Cotangent of an angle is the ratio of the base to the perpendicular height of a right-angle triangle.

Thus : $\frac{\text{Base}}{\text{Perp.}}$ = cotangent, usually written cotan.

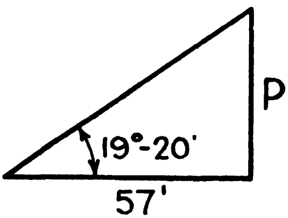
Example.—Given base = 57 in., perp. = 20 in.

$\frac{57}{20} = 2{\cdot}85$. This ratio is called the cotan.

Referring to the Table marked "cotan," $2{\cdot}85 = 19°\text{-}20'$. Any right-angle triangle in which the length of the base divided by the length of the perpendicular gives a ratio of 2·85, will have a base angle of 19°-20′. Checking as before :



$B = \text{cotan } 19°\text{-}20' \times 20.$
(Ref. Table, cotan $19°\text{-}20' = 2{\cdot}8502$)
$= 2{\cdot}8502 \times 20 = 57{\cdot}0040 = 57$ in.
(nearest for practical use).



$$P = \frac{57}{\text{cotan } 19°\text{-}20'} = \frac{57}{2{\cdot}8502} = 19{\cdot}998$$
= 20 in. (nearest for practical use).

The Sine of an angle is the ratio of the perpendicular height to the hypotenuse (the side opposite to the right angle) of a right-angle triangle.

Thus : $\frac{\text{Perp.}}{\text{Hyp.}}$ = sine, usually written sin.

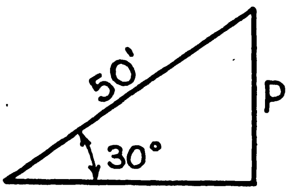
Example.—Given perp. = 25 ft., hyp. = 50 ft.

$\frac{25}{50} = \cdot 5000$. This ratio is called the sin.

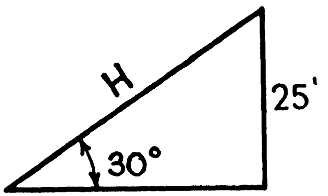
Referring to the Sin tables, ·5000 = 30°.

Any right-angle triangle in which the length of the perpendicular, divided by the length of the hypotenuse, gives a ratio of ·5000, will have a base angle of 30°.

Checking as before :



$$\begin{aligned} P &= \sin 30^\circ \times 50 \\ &\quad (\text{Ref. Table, } \sin 30^\circ = \cdot 5000) \\ &= \cdot 5000 \times 50 \\ &= 25 \text{ ft.} \end{aligned}$$



$$\begin{aligned} H &= \frac{25}{\sin 30^\circ} \\ &= \frac{25}{\cdot 5000} \\ &= 50 \text{ ft.} \end{aligned}$$

The Cosine of an angle is the ratio of the base to the hypotenuse of a right-angle triangle.

Thus : $\frac{\text{Base}}{\text{Hyp.}}$ = cosine, usually written cos.

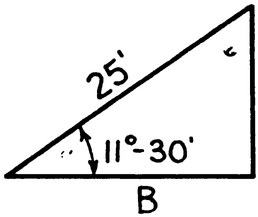
Example.—Given base = 24 ft. 6 in., hyp. = 25 ft.

$\frac{24 \cdot 5}{25} = \cdot 9800$. This ratio is called the cos.

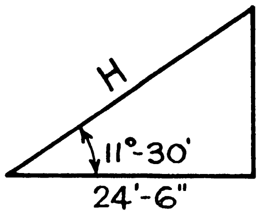
Referring to the Cosine tables, ·9800 = 11°-30′.

Any right-angle triangle in which the length of the base, divided by

the length of the hypotenuse, gives a ratio of ·9800, will have a base angle of 11°-30′. Checking as before :



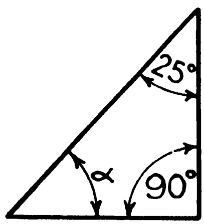
$B = \cos 11°\text{-}30' \times 25$
(Ref. Table, $\cos 11°\text{-}30' = \cdot 9800$)
$= \cdot 9800 \times 25$
$= 24{\cdot}5$ ft.



$$H = \frac{24{\cdot}5}{\cos 11°\text{-}30'} = \frac{24{\cdot}5}{\cdot 9800} = 25 \text{ ft.}$$

In connection with this subject, it is necessary to remember that the sum of the three angles in any triangle equals 180°. When dealing with a right-angle triangle, one angle is always known, the right angle, 90°. Therefore, the sum of the remaining two angles is 90°.

Example.—To find base angle in a right-angle triangle, having a top angle 25° :



$90° - 25° = 65°$
$\alpha = 65°$

Chapter VI

HAND-MEASURING TOOLS

Rules

THE commonest hand-measuring tool is the Standard steel rule. These can be obtained in various lengths, from 1 in. to 48 in., and graduated over a very wide range, including the Metric Standard. The usual British Standard includes $\frac{1}{64}$ in., $\frac{1}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{8}$ in. They may be flexible or semi-flexible steel, the stainless-steel rules now becoming very popular.

Rule Holders

The type shown in Fig. 18 is used in conjunction with short steel rules, and holds the latter at an angle of 30°. The rule is locked in position

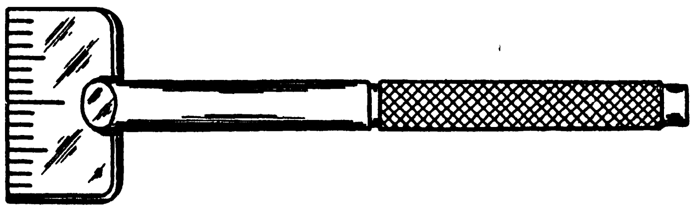


Fig. 18.—RULE HOLDER

by a turn of the knurled handle. This tool is useful for measuring small work, such as keyways and recesses, and can be used more conveniently than the usual rule during the actual machining operations.

Calipers

Where only approximate measurements are being checked, inside and outside calipers are useful. The size is taken on the calipers, and then measured on a steel rule.

As no direct reading is made on the calipers themselves, and accuracy cannot be expected beyond $\frac{1}{100}$ in., the inspector must cultivate "feel," that is, the ability to judge how hard the points of contact touch the work, and how much spring exists in the caliper legs.

Figs. 19 and 20 show the ordinary "friction-joint" calipers. This

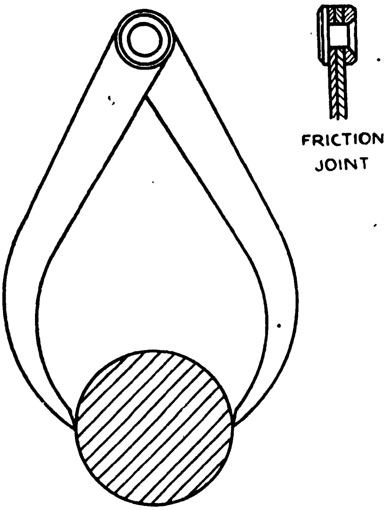


Fig. 19.—Taking an outside diameter

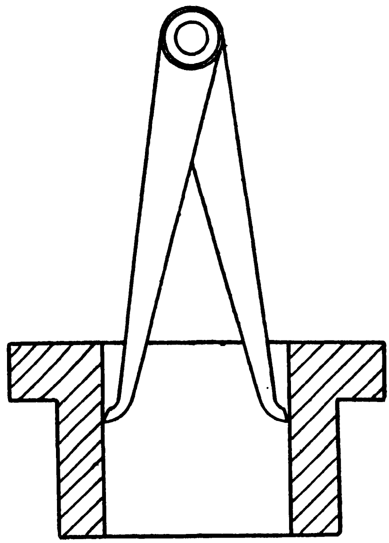


Fig. 20.—Taking an inside diameter

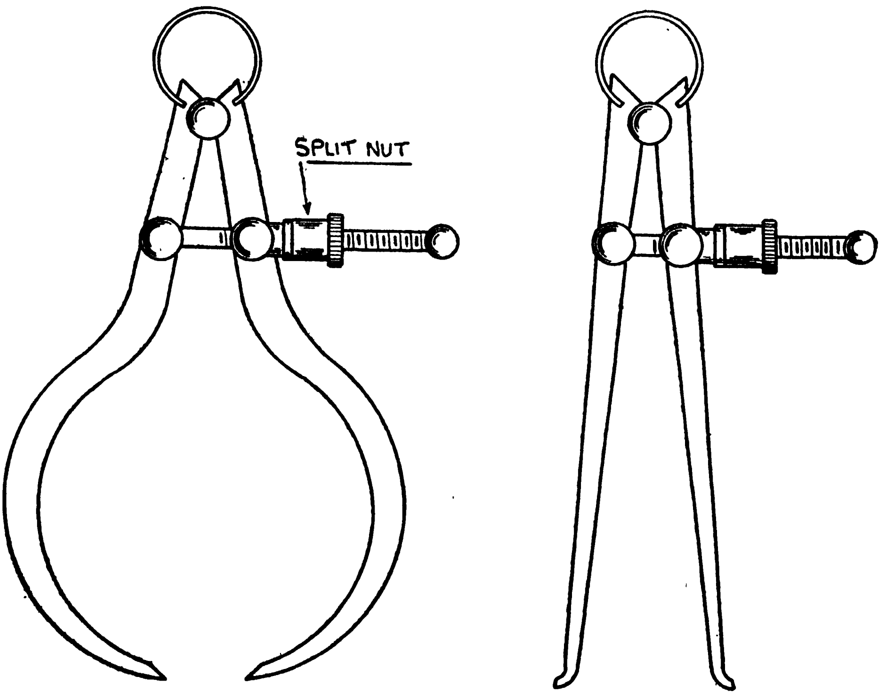


Fig. 21.—Spring calipers

type of caliper, for small measurements, should never be opened out by hand forcing, but by tapping the back of the joint on a wooden block. Similarly, the legs should be closed by holding one leg in the fingers and tapping the other on a wooden block.

Fig. 21 shows an improved form, the spring calipers. The legs are adjusted by means of a knurled split nut, which engages the screw at the slightest pressure, and upon withdrawal of the pressure the nut slides freely over the outside of the screw. When using these calipers, the legs should be pressed together by the fingers against the spring pressure whilst adjusting the split nut. This obviates the tendency of undue wear on the thread of the nut.

Another type is shown in Fig. 22—the inside and outside lock-joint

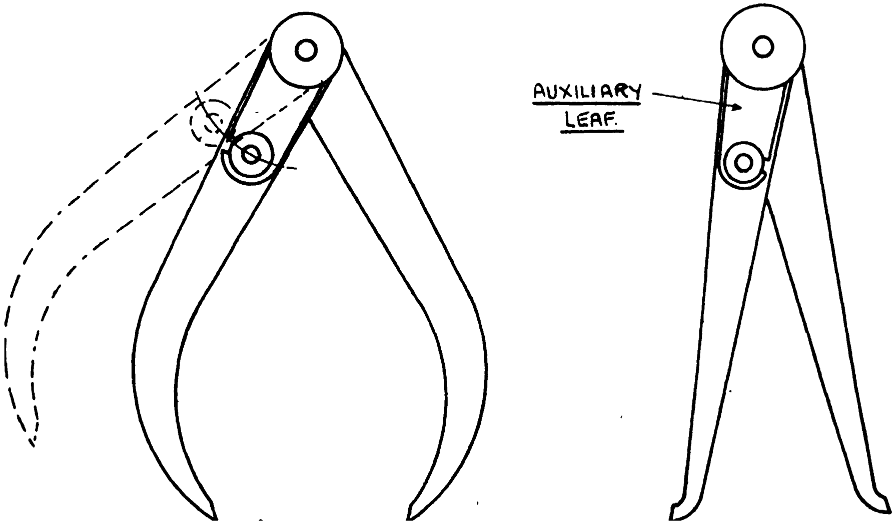


Fig. 22.—LOCK-JOINT TRANSFER CALIPERS

transfer calipers. These can be used for measuring inside cavities and over outside projections.

When taking the size the joint is locked, and for removing the calipers to measure this size the nut binding one arm to the auxiliary leaf is loosened. The arm can then be moved inward for inside calipers and outward for outside calipers, thus clearing the obstruction. The arm is moved back against the stop for measuring the size.

Depth Gauges

Fig. 23 shows the simplest form of depth gauge. This tool is used

for measuring the depth of "blind" holes, the distance from a plane surface to a projection, etc. The gauge consists of a head and an adjustable graduated steel blade, the latter being adjusted by hand and held in position by a small knurled screw.

Micrometer and Vernier depth gauges are dealt with in Chapter VII.

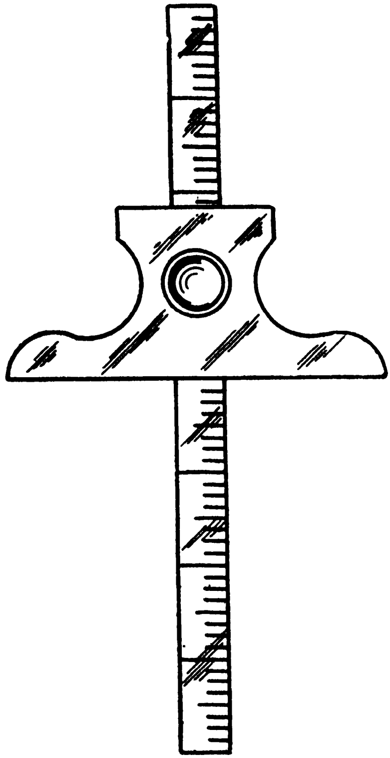


Fig. 23.—Simple Depth Gauge

Feeler Gauges (Fig. 24)

These consist of a varying number of steel leaves of various thicknesses, arranged after the manner of a penknife. A most convenient size is one having 22 leaves, the thinnest being ·001 in. Each leaf is marked with its thickness, in thousandths of an inch, and can be used singly or built up into the required combination. Care must be taken, especially with the thinner leaves, to prevent damage, and it is also important to keep these clean to ensure correct readings.

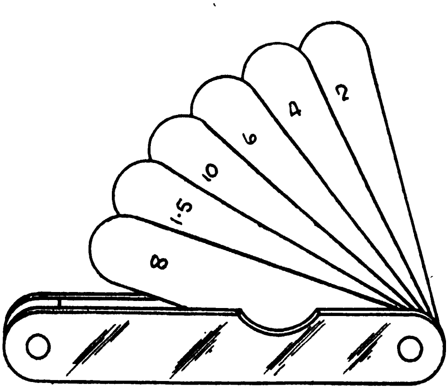


Fig. 24.—Feeler gauges

Fillet Gauge (Fig. 25)

This is also called a radius gauge, and consists of a number of steel gauges of convex or concave form. They are especially useful for laying out special forming tools, in addition to checking fillets or radii.

Where special fillets have to be checked, a profile gauge is often made, which is applicable to the particular component.

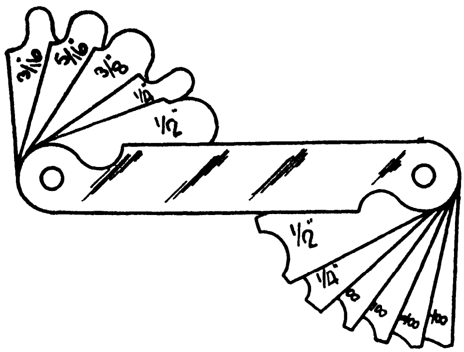
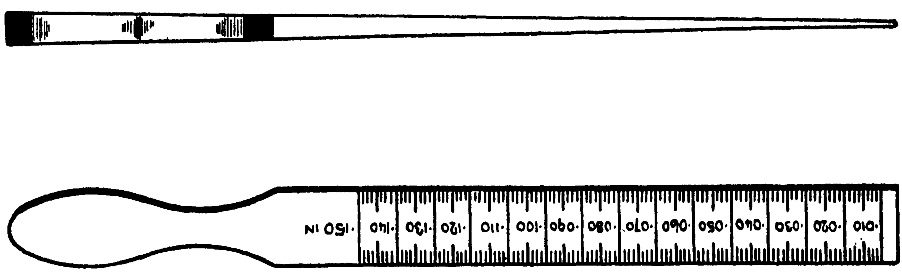


Fig. 25.—FILLET OR RADIUS GAUGE

Taper Gauge

This is shown in Figs. 26 and 27, and consists of either a single or series of hinged tapered steel blades, graduated in thousandths of an inch, or for less accurate work, in fractions of an inch. Also, gauges graduated to the Metric system are obtainable.

They are used for measuring the width of slots, inside diameters, gaps between components, etc.



Figs. 26 *and* 27.—TAPER GAUGE

Wire Gauges

The commonest form (Fig. 28) is the flat circular steel disc, having a series of slots around the periphery. The parallel width of the slot equals the diameter of the wire whose gauge size is indicated. These gauges are made to suit the various wire-gauge systems.

Fig. 29 shows another form of wire gauge, combining a sliding caliper device for measuring the diameter of the wires, or the thickness of sheet metal.

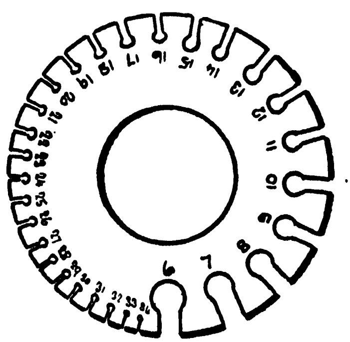


Fig. 28.—STANDARD WIRE GAUGE

The taper wire gauge is shown in Fig. 30. The wire is measured by placing it in the V opening until it touches both sides of the V, when the division on the scale at the point of contact indicates the gauge size.

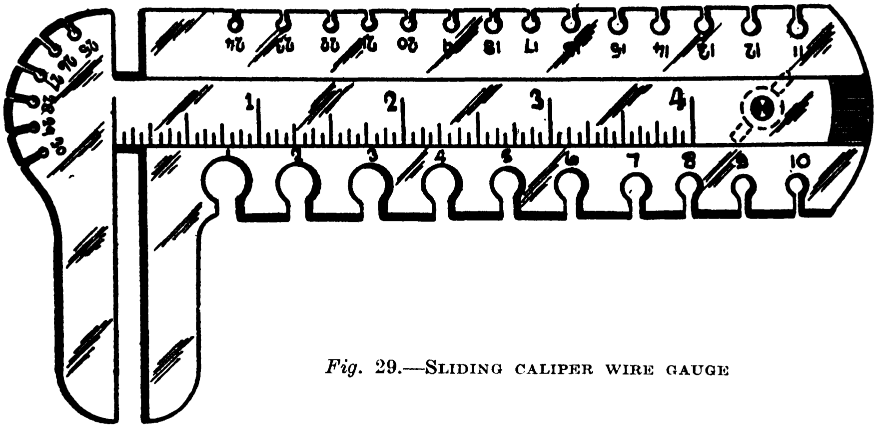


Fig. 29.—Sliding caliper wire gauge

Surface Gauge, or Scribing Block

Two common types are indicated in Figs. 31 and 32. The simplest form is a vertical steel pillar, fitted into a heavy base. The scriber is adjusted by means of a knurled nut.

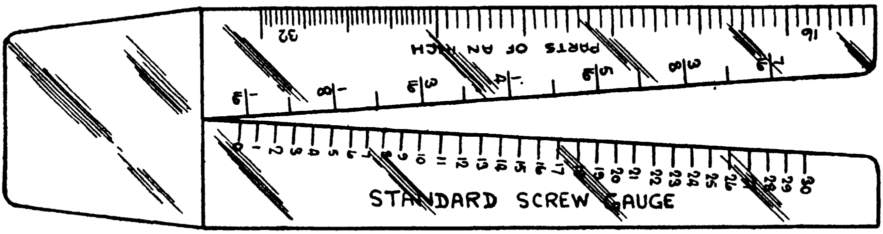


Fig. 30.—Taper wire gauge

The improved form is the Universal surface gauge, which has a V groove in the base, and allows the gauge to be used on round stock in addition to flat surfaces. The scriber is adjusted by means of a knurled nut, as with the simpler form, but the vertical pillar can be adjusted to any desired angle by means of the knurled nut *A*, and the final adjustment made by the use of the knurled nut at front of base. Two gauge pins are provided in the base, which can be pushed down and act as a

guide against the edge of the surface plate. The surface gauge is mainly used in conjunction with a surface plate when checking components.

These gauges can be used to advantage for checking castings and pressings, where extreme accuracy is not required. Also, the surfaces to be checked can be either vertical, horizontal, or angular.

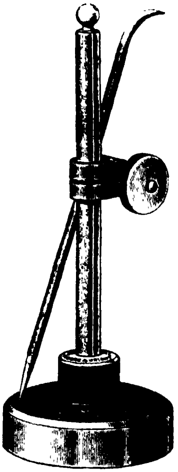


Fig. 31.—SIMPLE SURFACE GAUGE

(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

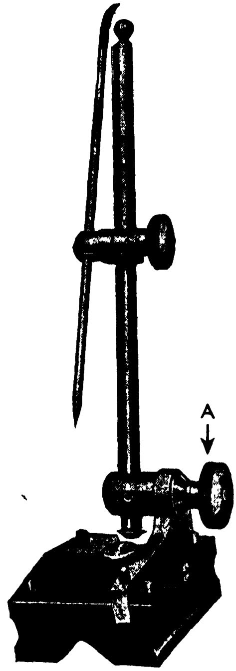


Fig. 32.—UNIVERSAL SURFACE GAUGE

(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

Dial Gauges, or Dial Test Indicators

These popular and accurate instruments are used for checking parallelism and concentricity of rods, surface flatness, and concentricity of bored holes, etc.

Most forms of this type of gauge are alike, the only difference being the method of converting the linear motion of the spindle, or plunger, to the rotary motion of the pointer. Pressure on the plunger causes the pointer to move round the dial, in proportion to the plunger's movement.

The commonest type of dial (Fig. 33) is divided into 100 equal divisions, each of ·001 in. ; every tenth division is shown longer on the scale and marked 0, 10, 20, 30, etc., up to 90. The plunger movement is ·2 in., which gives two complete revolutions of the pointer, each equal to ·1 in. linear plunger movement. The object of the double range is to give a plus and minus movement from a given datum line.

Another common type of gauge has a plunger movement of ·3 in., and the scale on the dial graduated from 0 to 25 and then from 25 back to zero (Fig. 34). As one complete revolution of the pointer represents ·05 in. (fifty thousandths), six revolutions cover the full range of the plunger ; thus : $6 \times \cdot 05 = 30$ in. One side of the dial is marked plus and the other minus, thus giving a clear indication of the reading. The scale is graduated in ·0005 in. (half thousandths), or to hundredths of a millimetre.

The usual range of dial gauges varies from $1\frac{1}{8}$ in. to $3\frac{5}{8}$ in. diameter, the plunger travel from ·2 to ·5 in., and readings from 0 to 100, or 25–0–25 and 50-0-50. Graduations are obtainable from ·001 in. to ·0001 in., and from ·01

mm. to ·001 mm. Other sizes are available for special requirements.

Models embodying a counter have the advantage that the number of revolutions of the pointer are automatically recorded.

Another very useful accessory when measuring to predetermined tolerances is the use of tolerance pointers (Fig. 35). These can be instantly adjusted to any required position by means of knurled screws on the centre of the crystal.

In cases where it would be impossible to use the standard gauge, right-angle and straight levers can often be employed to advantage (Fig. 36).

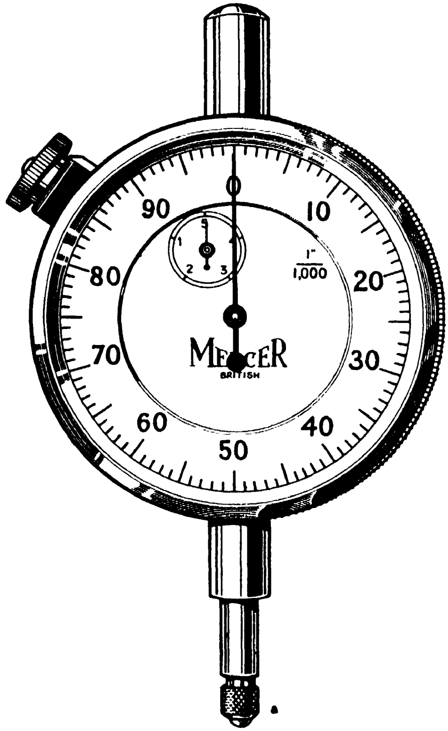


Fig. 33.—DIAL GAUGE
(*By courtesy of J. E. Baty & Co.*)

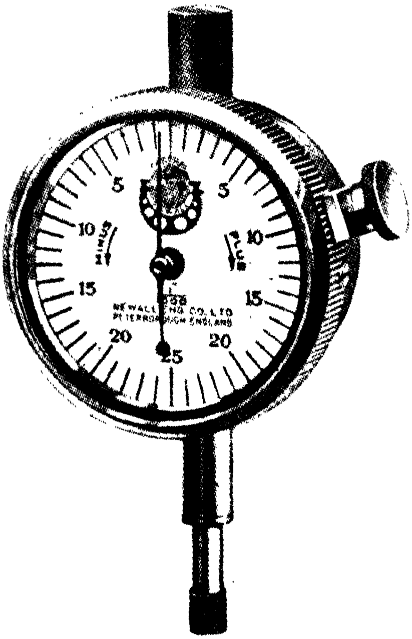


Fig. 34.—25–0–25 FEDERAL-NEWALL DIAL GAUGE
(*By courtesy of The Newall Engineering Co., Ltd.*)

The back of the gauge can be either flat, or provided with a lug for clamping to a stand or the vertical pillar of a surface gauge.

Various means are employed to set the pointer to zero. This must always be checked before starting to take readings. The usual methods are by special zero adjusting screw, by turning the knurled outer rim, or by slip gauges.

Special-purpose Dial Gauges

Fig. 37 shows a special gauge for measuring sheet materials,

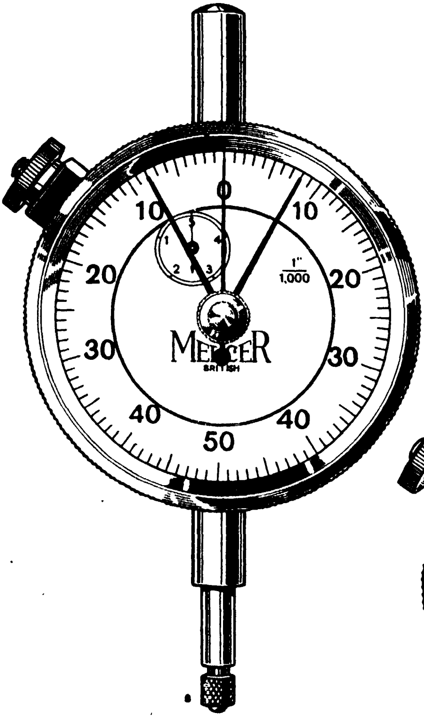


Fig. 35.—Tolerance pointers
(*By courtesy of J. E. Baty & Co.*)

such as mica, celluloid, and sheet metal of every description. The model illustrated is fitted with a lever for raising and lowering the plunger under spring pressure, but a "push-down" plunger operated by finger pressure is also available. The capacity of this gauge is ·5 in., reading either in ·0005 in., ·001 in., or ·01 mm. The gauge illustrated is provided with a clamp for arranging in the most convenient position.

Another similar type is shown in Fig. 38, for measuring away from the edge of the material, and is of the same capacity as before, but with a throat size of 4 in.

A bench model is shown in Fig. 39, having a throat size of either 12 or 18 in. Incorporated is an adjustable work stop for facilitating the measurement of large sheets.

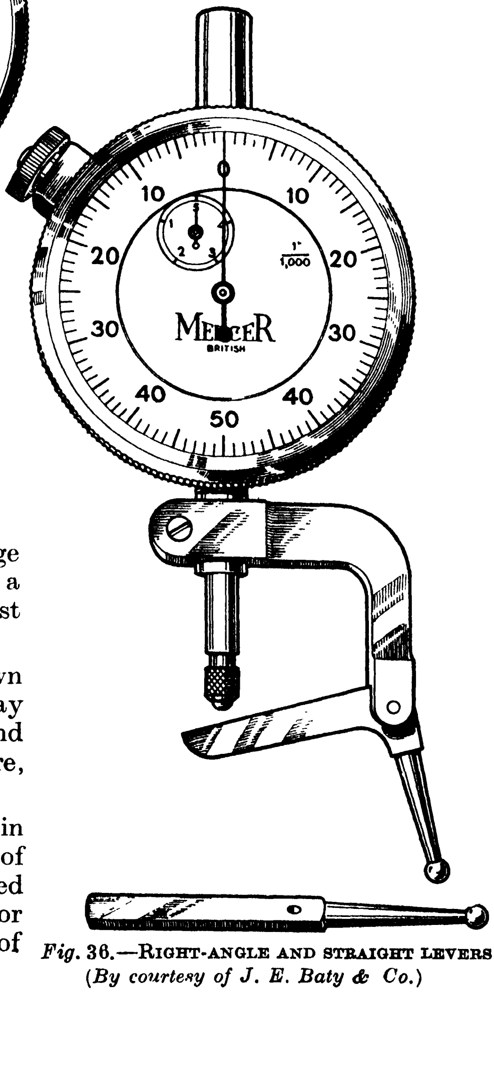


Fig. 36.—Right-angle and straight levers
(*By courtesy of J. E. Baty & Co.*)

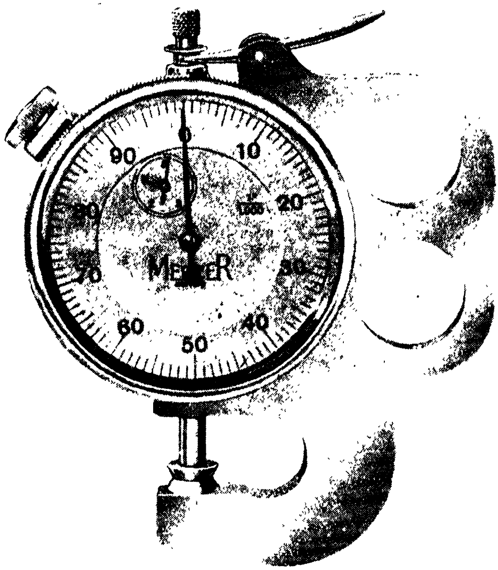


Fig. 37.—DIAL MICROMETER FOR STRIP AND SHEET MATERIALS
(*By courtesy of J. E. Baty & Co.*)

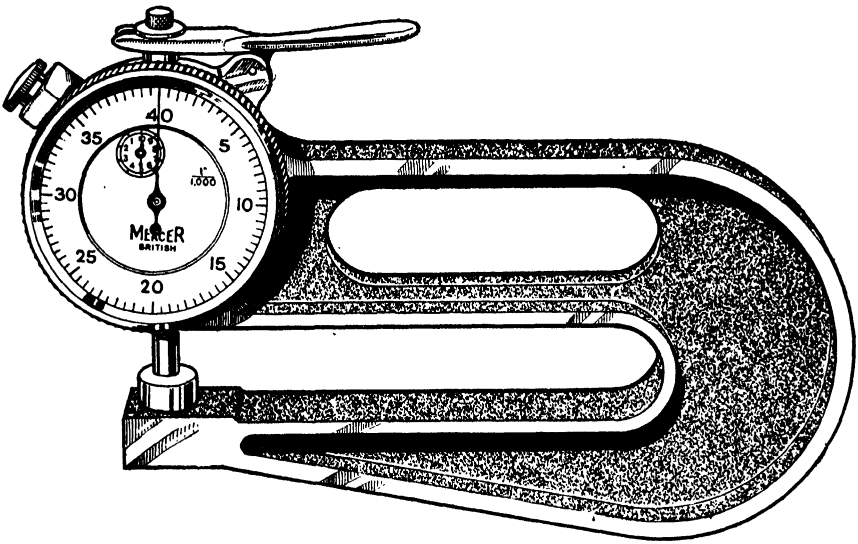


Fig. 38.—DIAL MICROMETER HAVING 4-IN. THROAT
(*By courtesy of J. E. Baty & Co.*)

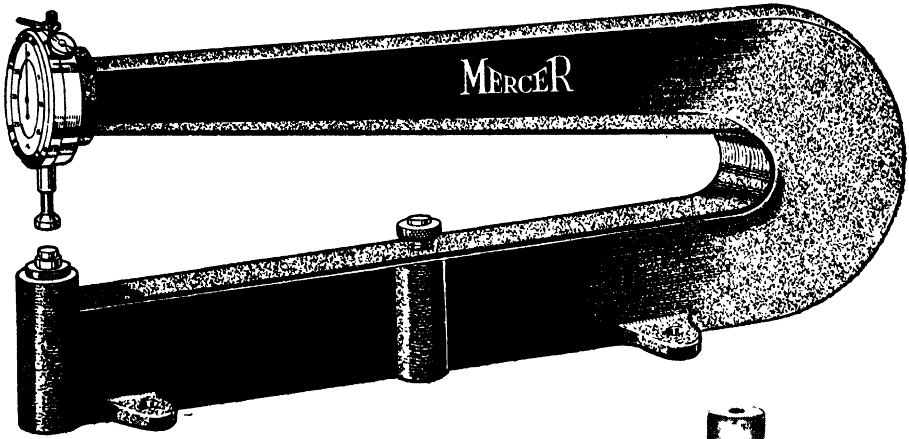


Fig. 39.—BENCH MODEL DIAL THICKNESS GAUGE
(*By courtesy of J. E. Baty & Co.*)

For checking and measuring small components, a gauge as shown in Fig. 40 can be most satisfactorily employed. Coarse or fine vertical adjustment is incorporated.

A very useful dial indicator for the rapid checking of castings, forgings, sheet metal, and for which any measurement would ordinarily be taken by means of outside calipers, is illustrated in Fig. 41. The jaws are made to special designs where required for particular purposes.

Universal Dial Test Indicator

This instrument allows full adjustment to any position for measurement and inspection in most inaccessible places. The dial is adjustable to the easiest reading position. It can be used

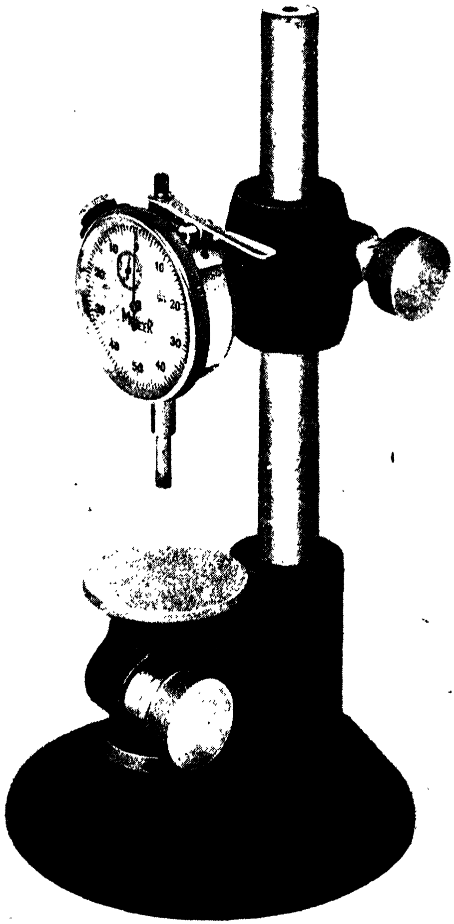


Fig. 40.—UPRIGHT COMPARATOR
(*By courtesy of J. E. Baty & Co.*)

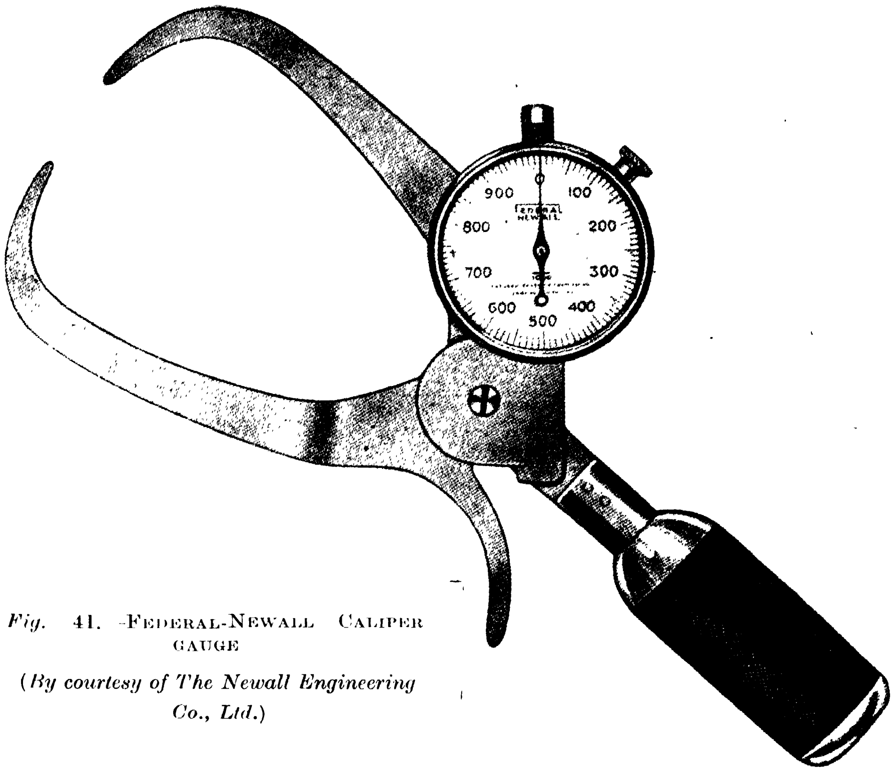


Fig. 41. —FEDERAL-NEWALL CALIPER GAUGE

(*By courtesy of The Newall Engineering Co., Ltd.*)

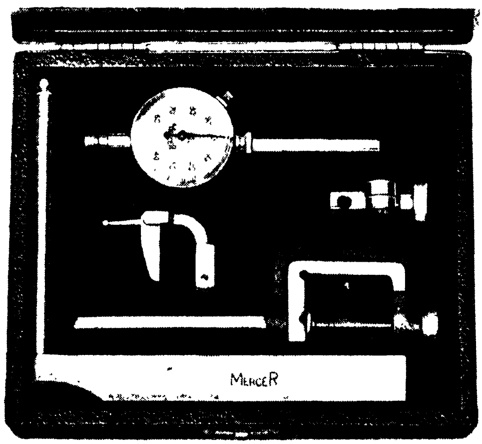


Fig. 42

UNIVERSAL DIAL TEST INDICATOR IN CASE

(*By courtesy of J. E. Baty & Co.*)

on surface gauge pillars, tool posts, or quickly adapted to special fixtures. Fig. 43 shows a model having a universal holding bar, and the contact point is arranged to swivel, allowing for setting in any desired position. The motion of the contact point is reversible by means of the small lever, seen positioned behind the dial on the upper right. The contact points are interchangeable, according to the material being measured.

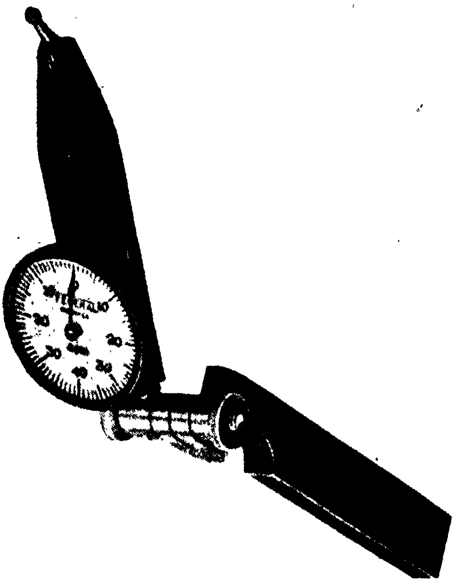


Fig. 43.—FEDERAL-NEWALL UNIVERSAL DIAL TEST INDICATOR

(*By courtesy of The Newall Engineering Co., Ltd.*)

In Fig. 42 is another arrangement of the Universal dial test indicator.

Cylinder Dial Gauges

An internal measuring device, covering a wide range, is given in Fig. 44. The range is obtained by the use of distance rods, and the capacity is for holes of $\frac{7}{8}$ in. to 2 in. diameter. The gauge is calibrated, either by ring gauge or micrometer, and the adjustable bezel provided with a clamp. The dial is graduated plus and minus each side of the zero line. In addition to the measuring point, three-point contact is provided, which is self-aligning in the bore. To show the true measurement on the dial, the gauging points are rocked over the axis of the bore.

Another type of cylinder gauge is shown in

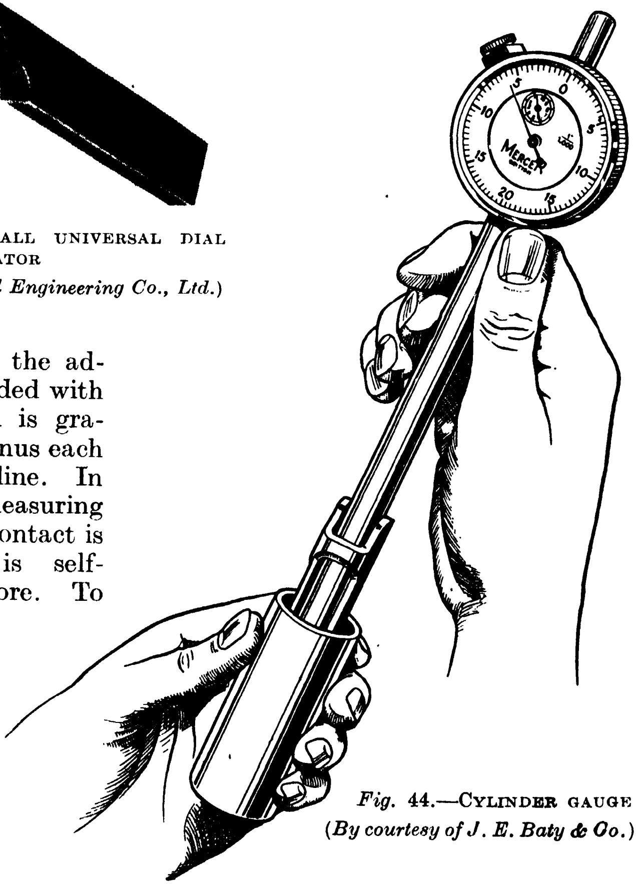


Fig. 44.—CYLINDER GAUGE

(*By courtesy of J. E. Baty & Co.*)

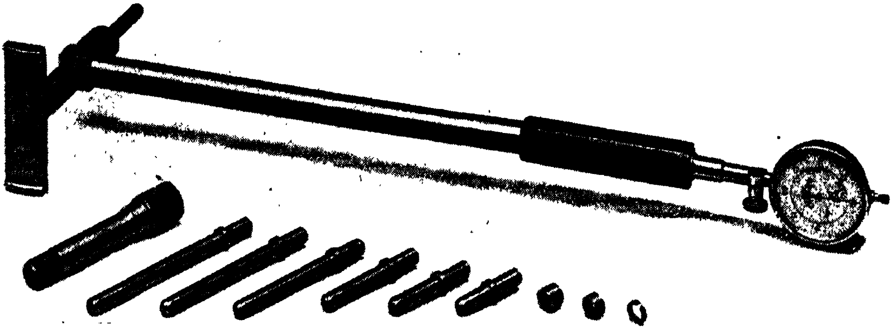


Fig. 45.—CYLINDER GAUGE GIVING A COMBINATION OF SIZES
(*By courtesy of J. E. Baty & Co.*)

Fig. 46. The capacity is 2 to 6 in., the variation being obtained by the use of distance rods. Inaccuracies, such as wear, out of roundness, taper, etc., are readily seen, and the gauge needs no setting. This instrument is self-aligning in the bore, and the measuring points are rocked over the axis, the latter being the correct acknowledged principle for bores of automobile engine cylinders, etc.

A further example is illustrated in Fig. 45, having a capacity of 6 in. to 36 in., and suitable for diesel oil, steam, marine cylinders, etc.

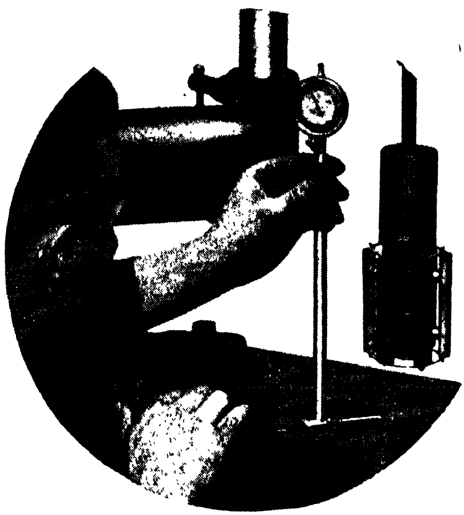


Fig. 46.—CYLINDER GAUGE IN POSITION
(*By courtesy of J. E. Baty & Co.*)

Chapter VII

MICROMETERS AND MICRO-MEASURING INSTRUMENTS

MICROMETERS

APART from the common steel rule, the micrometer caliper is probably the most indispensable instrument in modern engineering practice, and comes under the category of "precision instruments." The commonest type is capable of measuring to within the limits of $\frac{1}{1000}$ in.

Before explaining the construction and method of reading the micrometer, it is necessary to understand the principle on which the instrument is based.

Consider, first, an ordinary screwed bolt or rod. The pitch of a single-start thread can be defined as the distance from the crest of one thread to the crest of the next successive thread. A $\frac{1}{2}$-in. Whitworth screw thread has twelve complete threads to each inch of thread length, and the pitch of the thread is therefore ($\frac{1}{12}$ in.) Suppose the bolt is threaded into a nut, which is held stationary, then one complete turn of the bolt will cause the thread to move longitudinally, one pitch length, which in this case is exactly $\frac{1}{12}$ in. If the bolt is given only half a complete turn, the distance moved will be one-half of $\frac{1}{12}$ in., or $\frac{1}{12} \times \frac{1}{2}$, which is equal to $\frac{1}{24}$ in. A quarter of a turn will give $\frac{1}{12} \times \frac{1}{4}$, which is equal to $\frac{1}{48}$ in. From this it is seen that whatever fraction of a turn the bolt is given, the thread will move that fraction of the pitch. Thus, if a screw has 40 threads per inch, its pitch will equal $\frac{1}{40}$ t.p.i. $= \frac{1}{40}$ in. $= \cdot025$ in. or $\frac{25}{1000}$ in.

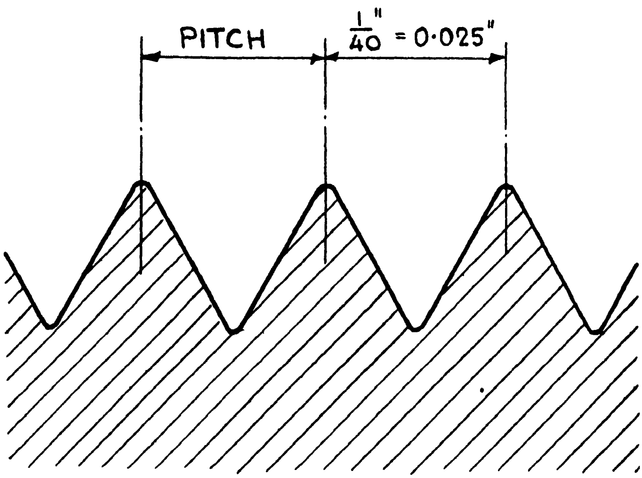


Fig. 47.—PITCH OF SCREW DEFINED

It is now necessary to get a clear understanding of the term "decimal equivalent." A decimal fraction is one in which the denominator is 10 or some power of 10. To convert a vulgar fraction, such as $\frac{1}{4}$, into a decimal fraction, the numerator 1 is divided by the denominator, thus : $1 \div 4 = \cdot 25$; and to convert the decimal ·25 again into a vulgar fraction, $\frac{25}{100} = \frac{1}{4}$. It is by this method that the decimal equivalents used in

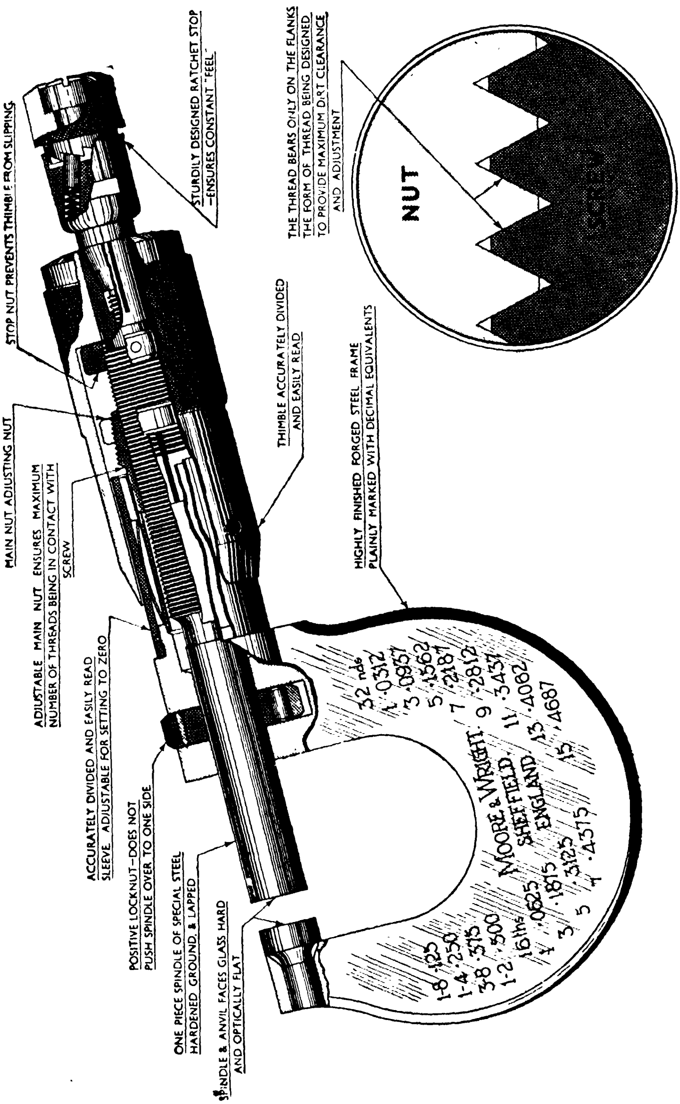


Fig. 48.—SECTION SHOWING PRINCIPAL POINTS OF MOORE & WRIGHT'S MICROMETER

connection with the micrometer are obtained, and the following should be committed to memory :

$\frac{1}{1000} = \cdot 001$ $\frac{1}{40} = \cdot 025$

$\frac{1}{100} = \cdot 01$ $\frac{1}{20} = \cdot 05$

$\frac{1}{10} = \cdot 1$ $\frac{3}{40} = \cdot 075$ etc.

Construction and Use of the Micrometer Caliper

Fig. 48 shows the various parts of the micrometer, of which the wearing parts are hardened, apart from the provision made for taking up wear on the internal threaded portion. By locking the spindle firmly, by means of the locking ring, a solid gap gauge can be formed to any required dimension within the limits of the micrometer's capacity.

When in use, the work is placed against the anvil and the spindle moved in to touch it. On nearing the work, the ratchet head should be used ; this prevents excessive pressure being put on the thimble. Where no ratchet head is provided, measurement is largely a question of " feel " ; and in all cases, the micrometer must be regarded as a precision instrument, and handled as such.

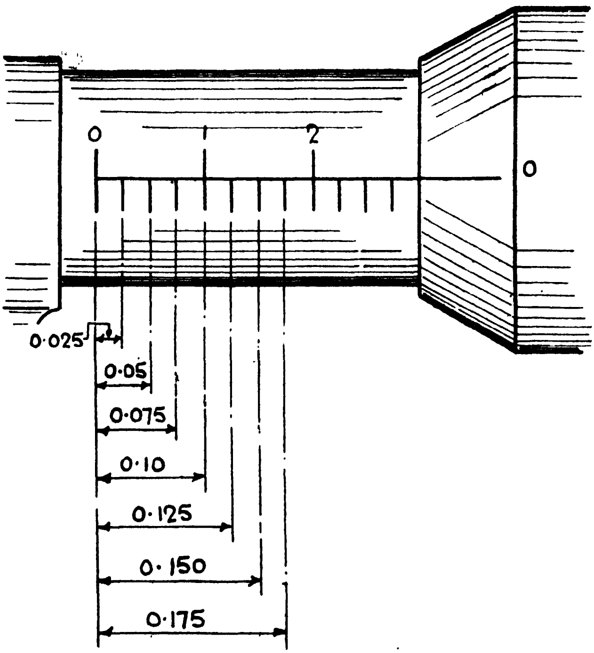


Fig. 49.—Showing graduations on sleeve

Micrometer Screw and Thimble

The spindle of the micrometer is threaded to 40 threads per inch, giving, therefore, a pitch of $\frac{1}{40}$ in. From this, it will be seen that one complete turn of the spindle will give a longitudinal movement of $\frac{1}{40}$ in. The thimble is divided into 25 equal parts ; therefore, if the spindle is turned one-twenty-fifth of a turn, the spindle will move one-twenty-fifth of one-fortieth, or $\frac{1}{25} \times \frac{1}{40} = \frac{1}{1000} =$ ·001. The sleeve is

graduated to correspond with the pitch of the spindle screw, i.e. in fortieths of an inch, each fourth graduation being numbered. Therefore, $\frac{1}{40} \times 4 = \frac{4}{40}$ $= \cdot 1$, which represents $\frac{1}{10}$ in. for each fourth graduation. The thimble, as previously mentioned, is divided into 25 equal parts, and each fifth graduation numbered, representing a given number of thousandths of an inch.

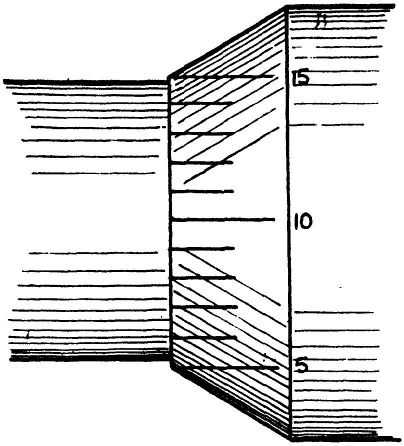
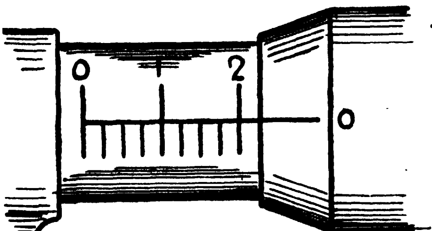


Fig. 50.—Showing graduations on thimble
Each space represents ·001 in.

Reading the Micrometer

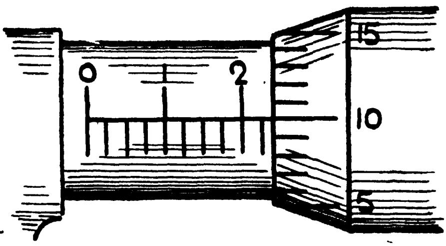
Note, first, the number of tenths and fortieths showing on the sleeve. Take, next, the number of thousandths on the thimble, reading from the datum line. Finally, add together these three readings, the result being the measurement of the component. Figs. 49 and 50 show the graduations on the sleeve and thimble, and Figs. 51 and 52 give examples from which any readings can be deduced.



TWO-TENTHS 0·2
ONE-FORTIETH 0·025

2/10 + 1/40 0·225

Fig. 51.—Reading sleeve with thimble at zero



0·2
0·025
0·010

0·235

Fig. 52.—Reading sleeve and thimble

The Ten-thousandth or Vernier Micrometer

For readings of $\frac{1}{10000}$ in., a special micrometer, having a vernier, or series of divisions on the sleeve, is used. These divisions number 10, and therefore eleven lines are scribed horizontally on the sleeve, which are numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, and occupy the same length on the

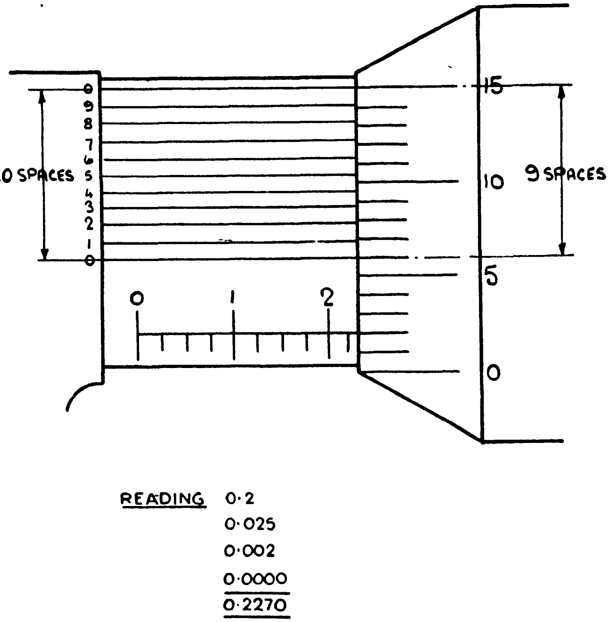


Fig. 53.—THE VERNIER MICROMETER

circumference of the sleeve as nine divisions on the thimble. Accordingly, when a line on the thimble coincides with a line on the vernier, the next two lines will differ by one-tenth, the next two by two-tenths, etc., until the last line on the vernier will coincide with a line on the thimble.

To read the micrometer, note first the thousandths as usual, with a standard instrument, then observe whether the zero line on the vernier coincides with a line on the thimble. If this is so, then the last line on the vernier will also coincide, and no ten-thousandth reading will require to be added to the thousandths, Should the zero line on the vernier not coincide with a line on the thimble, follow round the sleeve until the line is found which does, and this will be the number of ten-thousandths which must be added to

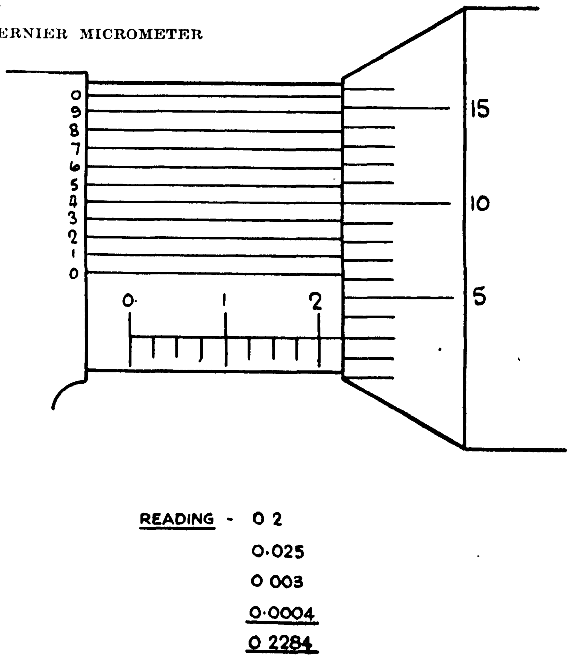


Fig. 54.—THE VERNIER MICROMETER

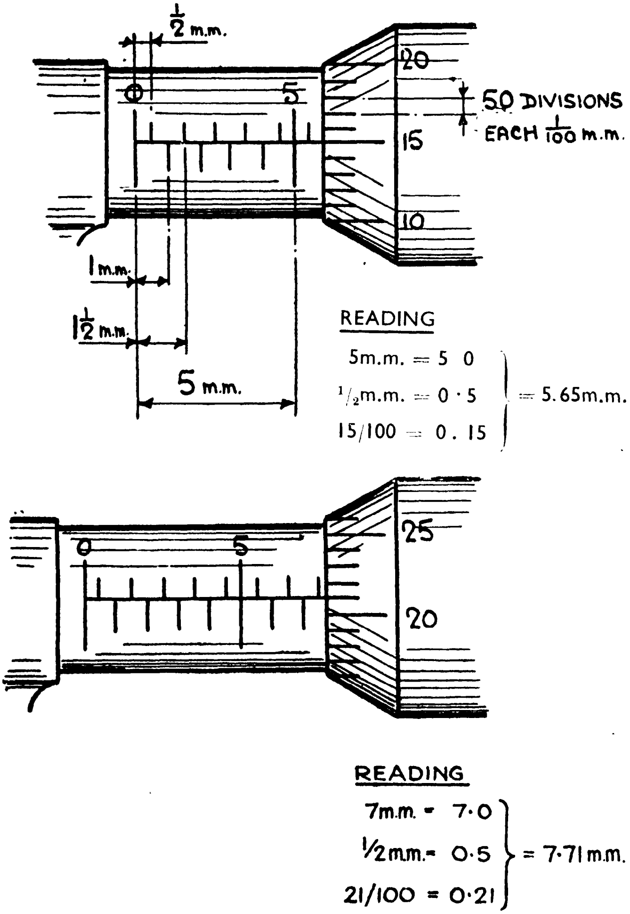
give the final measurement. Figs. 53 and 54 give examples from which any readings can be deduced.

The Metric Micrometer

The construction is the same as the English Standard micrometer, the difference being the pitch of the screw thread and the graduations on the sleeve and thimble. The pitch of the screw thread is $\frac{1}{2}$ mm., and two complete turns of the spindle are necessary to give a movement of 1 mm. The thimble is divided into 50 equal parts, and is engraved every fifth division, 0, 5, 10, 15, 20, etc. When fifty of these graduations have passed the zero line on the sleeve, the spindle, having made one complete revolution, has moved forward $\frac{1}{2}$ mm. Thus, when the spindle has moved only far enough for one graduation to pass the zero line on the sleeve, it will have moved forward $\frac{1}{50}$ of $\frac{1}{2}$ (or ·50 mm.), $\frac{1}{100}$ mm. or ·01 mm.

To read the micrometer, note first the number of millimetres showing on the sleeve, and see whether or not a half-millimetre division is visible beyond this graduation. Then determine the hundredths of a millimetre, by the line on the thimble coinciding with the horizontal or zero line on the sleeve.

Fig. 55 shows the method of



Figs. 55 *and* 56.—METRIC MICROMETER READINGS

graduating the sleeve and thimble, and Figs. 55 and 56 show examples from which any readings may be deduced.

Taking up Wear

Considerable use is bound to produce wear, and it is necessary that the inspector should know how to compensate for this. To check for wear, hold the frame firmly, and try to move the spindle endwise without turning it. If the spindle can be moved, wear is present and must be taken up immediately. The spindle should be unscrewed to the limit of its extension, and the wear on the thread taken up by means of the adjusting nut, which is to be found under the thimble. Correct adjustment has been achieved when the spindle rotates freely without end play. Some micrometers are provided with an adjustable anvil, which is secured by means of a setscrew. The adjustment is effected by loosening the setscrew and moving the anvil endwise.

Checking Zero Setting

This can be effected by screwing up the spindle until both gauging faces are just in contact. The zero line on the thimble should coincide with the datum line on the sleeve. If this is not so, by using the special spanner provided the sleeve should be adjusted until this position is attained.

Micrometer Capacity

The most popular size of micrometer is the small type, having a maximum opening of 1 in. Larger sizes are made, a complete set usually ranging from 0 to 12 in., and increasing in steps of 1 in. Sizes above this are obtainable, but generally are out of the requirements of ordinary practice. When using sizes over 1 in., it is the last inch which measures in thousandths and ten-thousandths. Thus in a 2-in. micrometer, the distance from 1 to 2 in. is measured in thousandths, and in the case of a 4-in. micrometer, from 3 to 4 in., and so on.

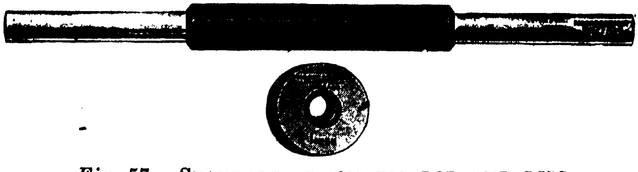


Fig. 57.—STANDARD MEASURING ROD AND DISC
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

To check for zero, in sizes over 1 in., it is necessary to have a standard for this purpose. In the smaller sizes this is usually in the form of a disc or roller, and for larger sizes a length gauge is used. For a 2-in. instru-

ment a 1-in. gauge is used, and for a 4-in. a 3-in. gauge, and so on. When the micrometer is set to zero, the gap should just pass the appropriate gauge.

Special-purpose Micrometers

To measure satisfactorily the thickness of soft materials, such as rubber, cloth and paper, etc., a special micrometer fitted with large flanges is used (Fig. 58).

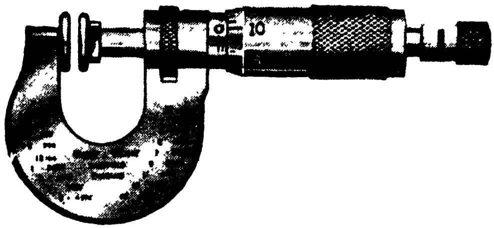


Fig. 58.—SPECIAL MICROMETER FOR PAPER AND SOFT MATERIALS

(*By courtesy of Moore & Wright* (*Sheffield*) *Ltd.*)

Curved Surfaces

The use of a standard micrometer for this purpose would obviously give an incorrect reading. To overcome this, a micrometer having either round-form spindle end and rounded anvil, flat spindle end and rounded anvil, or with pointed contact points is used. The latter type is also suitable for taking flute measurements (Fig. 59).

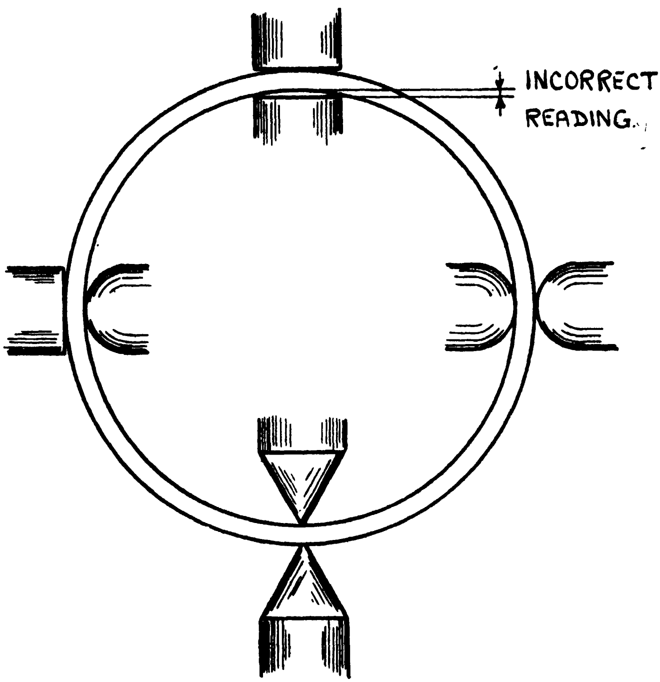


Fig. 59.—ANVILS AND SPINDLE ENDS FOR CURVED SURFACES

Measuring over Shoulders, in Channels, Keyways, etc.

The frame pattern (Fig. 60) is distinctly advantageous for this purpose, and the illustration shows its application.

Inside Micrometers

So far, out-

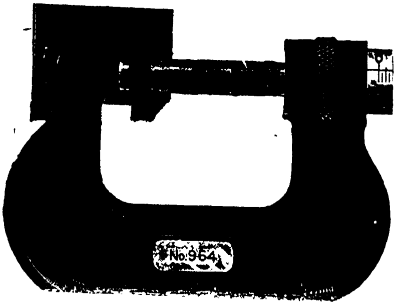


Fig. 60.—MICROMETER FOR MEASURING CHANNELS, ETC.
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

side micrometer calipers only have been considered. For internal and linear measurements, the inside pattern (Fig. 61) can be successfully employed. The essential parts of this set are the extension rods, each marked with the respective capacity; a micrometer head having ½-in. movement; and the distance piece ·500 in. long. Any size within the capacity of the set can be obtained by assembling the requisite rod and distance piece. To ensure accuracy, when setting, all joining faces must be clean, and the zero mark on the rods must be in line with the zero mark on the body.

Another form of internal micrometer is given in Fig. 62. This instrument has three measuring points, which are hardened and ground on their outer ends to spherical form, the diameter of the sphere being just below the smallest diameter in the range of the micrometer.

The three points are operated by means of a screwed spindle, contained in the body of the instrument. The range of this type varies from 2 to 2½ in., up to 11 to 12 in.

When in continual use, these micrometers should be checked periodically. The accepted method is by means of standard cylindrical ring gauges of the nominal size required.

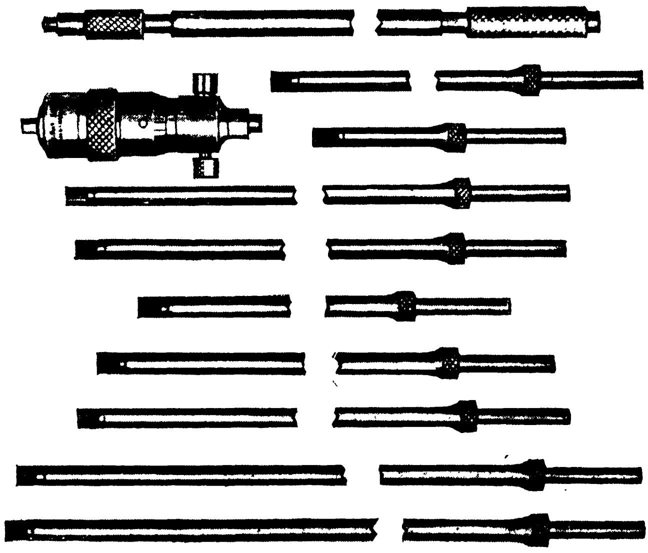


Fig. 61.—INSIDE MICROMETER AND EXTENSION RODS
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

Depth Gauge Micrometer (Fig. 63)

This instrument is used for accurately measuring the depth of holes and recesses,

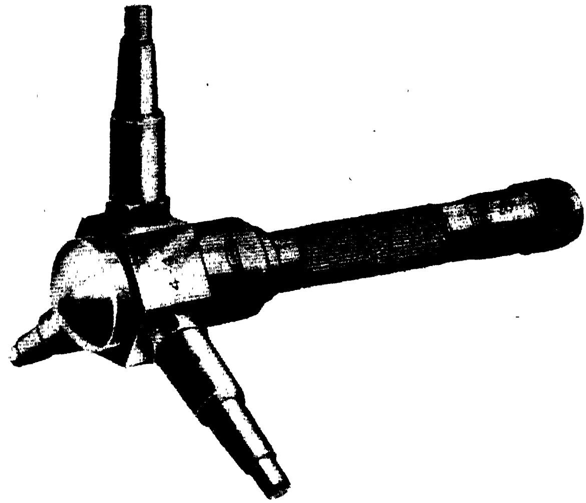


Fig. 62.—NEWALL INTERNAL MICROMETER
(*By courtesy of The Newall Engineering Co., Ltd.*)

etc. Care must be taken when the spindle bottoms the hole, or recess, to ensure that the base is not slightly lifted from its temporary seating. The illustration shows a depth-gauge reading up to 1 in., with a $2\frac{1}{2}$ by $\frac{1}{2}$-in. base.

For increased ranges, interchangeable extension rods are used, and are similar to those employed on internal micrometers. An example of this type is given (Fig. 64). The usual sizes are :

Capacity 0–3 in. with 3 extension rods. Base $2\frac{1}{2}$ in.
Capacity 0–3 in. with 3 extension rods. Base 4 in.
Capacity 0–6 in. with 6 extension rods. Base $2\frac{1}{2}$ in.
Capacity 0–6 in. with 6 extension rods. Base 4 in.

Solex Pneumatic Micrometer (Fig. 65)

This instrument has found considerable favour in the automobile and aeronautical industries, where very accurate gauging is essential in respect of cylinder bores, etc. As there is no actual contact between the measuring faces of the gauge and the component, the problem of wear, as experienced with plug, ring, or slip gauges, is overcome. The measurement is indicated by the difficulty which compressed air experiences in escaping from jets separated from the component by a fraction of a thousandth of an inch. Reference to the diagrammatic sketch will assist in understanding the underlying principle of this special micrometer.

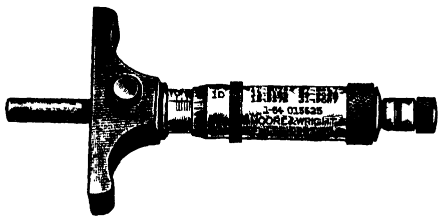


Fig. 63.—DEPTH-GAUGE MICROMETER
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

Compressed air is admitted to the top of a tube, which in turn is

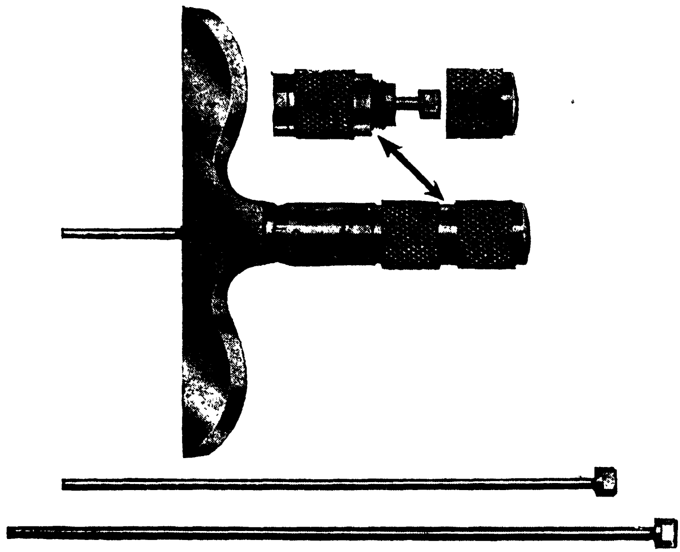


Fig. 64.—DEPTH-GAUGE MICROMETER WITH RODS FOR INCREASED RANGES

(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

connected at the base to a water-filled chamber. The surplus air escapes through another tube, immersed at a constant depth in the water chamber, thus maintaining a constant pressure in the upper chamber. A further tube is connected either to a special plug gauge, provided with jets around its walls, or to the inside faces of the blocks of a snap gauge.

The air escapes through the jets near the face which contacts the component. If the component is of correct size, a definite amount of air escapes through these jets, and the air pressure is indicated on the scale, being determined by the water level in the glass tube. Assuming the component is oversize in the vicinity of a jet, obviously more air will escape, owing to the increased clearance, and consequently the air pressure will fall. Also, if the component is undersize, the pressure will rise.

As the variation in pressure is directly proportionate to the variation in clearance, it is possible to measure the latter by means of the calibrated scale.

The accuracy of the micrometer is such that variations in measurement are magnified 9000 times, and measurements can be taken to within $\frac{1}{1000}$ in.

A special sensitive instrument is available for tool-room work, and enables measurements to ·000002 in. to be read, thus enabling standard gauge blocks to be checked.

The Vernier Caliper

The Vernier was originated by a Frenchman, Pierre Vernier, about

A.D. 1630, and consists of an auxiliary scale which is made to slide along the main scale of the measuring instrument.

A typical sliding vernier caliper is illustrated in Fig. 66.

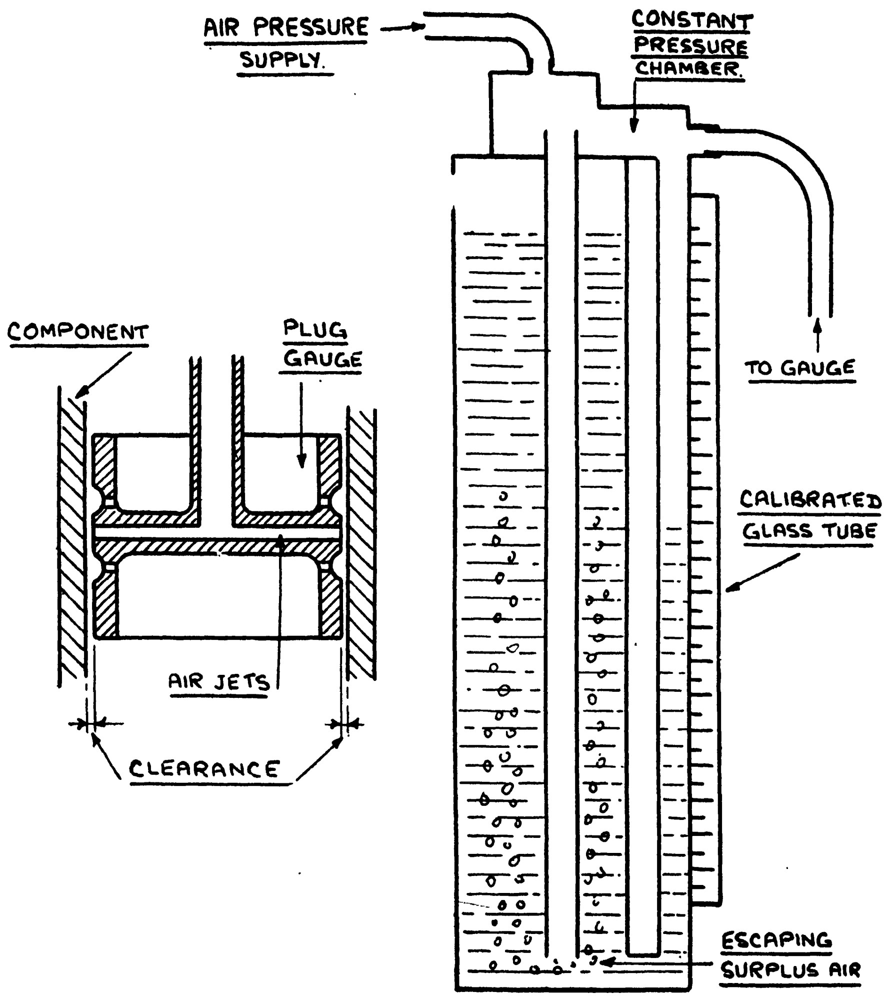


Fig. 65.—SOLEX PNEUMATIC MICROMETER

The One-hundredth Vernier Caliper (Figs. 67 and 68)

The main scale consists of a rule, graduated in inches and tenths of an inch. A sliding frame carries the vernier scale, which is only $\frac{9}{10}$ in.

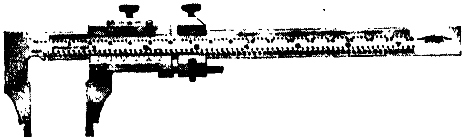


Fig. 66.—Vernier caliper gauge
(*By courtesy of James Chesterman & Co., Ltd.*)

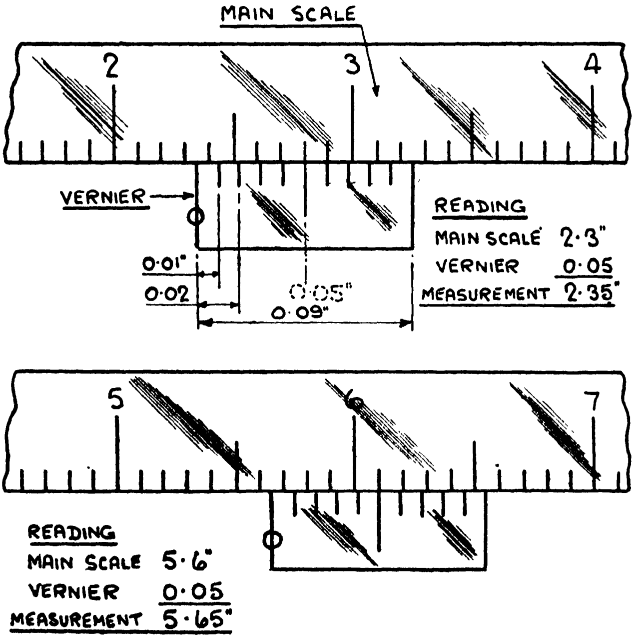
long, and divided into 10 equal parts, therefore each division must be less than $\frac{1}{10}$ in. by $\frac{1}{100}$ in.

To read the one-hundredth vernier, note the number of inches from the zero end of the main scale to the zero line on the vernier. Now take the number of tenths from this figure to the zero line on the vernier. By finding the division on the vernier which coincides with a division on the main scale, and adding this to the two previous readings, the final measurement is obtained. Examples are given in Figs. 67 and 68.

The Thousandth Vernier Caliper (Fig. 69)

The main scale is graduated in inches, tenths, and one-quarter of tenths (as in the case of the one-thousandth micrometer). The vernier length equals 24 of the smallest divisions on the main scale, i.e. 24 × ·025, and the edge of the vernier is divided into 25 equal parts. Therefore, each small division on the vernier is less than each division on the main scale by $\frac{1}{1000}$ in.

To read the one-thousandth vernier caliper, note the number of inches, tenths, and quarters of tenths that the zero line on the vernier has moved from the zero line on the main scale. Now find the division on the vernier which coincides with a division on the main scale, and add the results together to give the final measurement. An example is shown in Fig. 69.



Figs. 67 *and* 68.—Examples of reading 100th vernier caliper

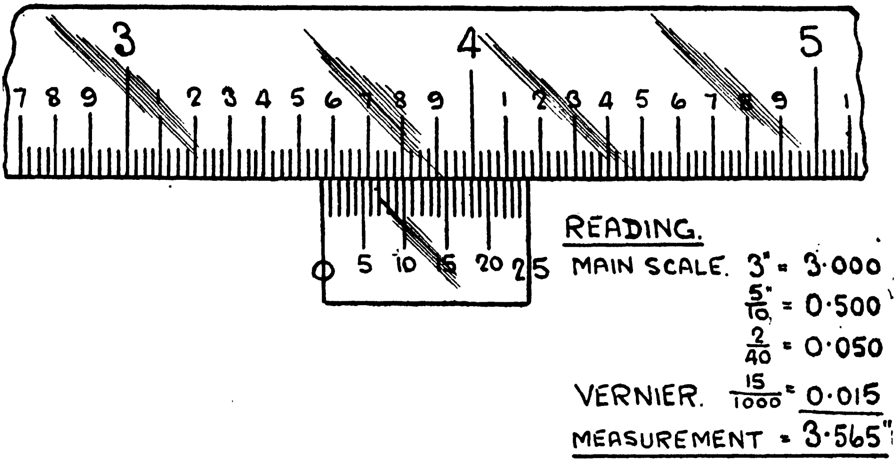


Fig. 69.—EXAMPLE OF READING 1000TH VERNIER CALIPER

The Sixty-fourth Vernier Caliper (Fig. 70)

The main scale is graduated in inches and $\frac{1}{8}$ in. The vernier is $\frac{7}{8}$ in. long, and divided into eight equal parts.

To read, note the number of inches and eighths of an inch through which the vernier zero line has moved from the main-scale zero line. Then find the coinciding line on the vernier, with the main scale, and add together the three readings to obtain the final measurement. An example is shown in Fig. 70.

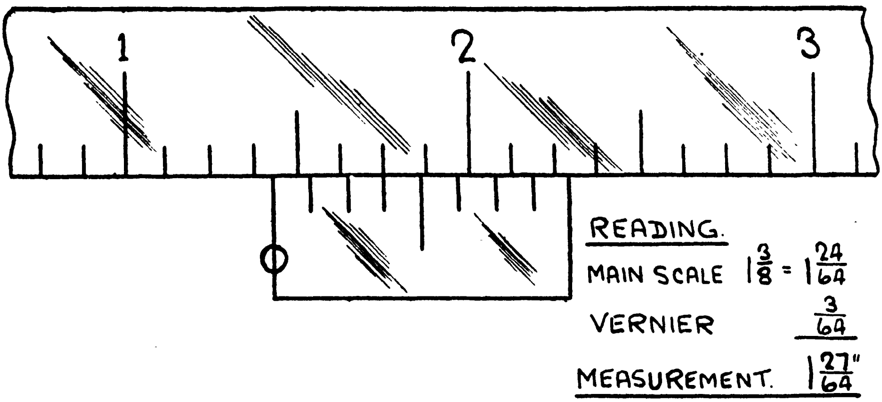


Fig. 70.—EXAMPLE OF READING $\frac{1}{64}$TH VERNIER CALIPER

Using the Vernier Caliper

Most vernier calipers are graduated for outside measurements, but in some cases one side of the main scale is set for outside and the other side for inside measurements, enabling the measurement to be read directly off the caliper. Where the caliper is set for outside measurement only, i.e. when the reading is zero with the jaws closed, and inside measurements are being taken, the width of the gauging faces on the jaws must be added to the final reading. The actual width is sometimes engraved at the gauging faces, otherwise this must be ascertained by checking with a micrometer.

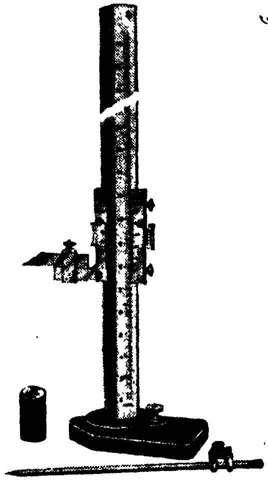


Fig. 71
VERNIER HEIGHT GAUGE
(By courtesy of James Chesterman & Co., Ltd.)

Vernier Height Gauge (Fig. 71)

This gauge consists of a vertical graduated scale supported in a heavy base. The vertical scale, or beam, carries the sliding vernier, provision on which is made to accommodate a special scriber. The latter is very useful for direct marking off, and saves taking the measurement from a separate rule and transferring to the component by means of the surface gauge. Height measurements are taken on gauging surfaces, of which several methods are available, and the measurement read as with the vernier caliper.

Vernier Depth Gauge

This gauge is used in the same manner as the simple depth gauge (Fig. 23), and the measurement is read by the same method as for the vernier caliper gauge.

Chapter VIII

LIMIT GAUGING AND GAUGES

WITH the advent of mass-production methods, it became necessary to devise some speedy and accurate form of checking the components at all stages of their manufacture, to ensure interchangeability of the finished component with its mating part. Also, satisfactory assembly must be assured without the necessity of having to fit each part independently.

The Limit Gauging system was first devised by Le Blanc, a Frenchman, in 1785, and adopted by Whitney in the U.S.A. in 1798.

The benefits of this system are seen nowadays in practically every mechanical product. A common instance is the automobile. When spares are necessary, it is a foregone conclusion that they will assemble, although they may have been manufactured at any distant period from that of the original mating part.

To arrive at this satisfactory state, the exact size of the finished components has to be established, and production and inspection methods so developed to ensure conformity of the dimensions.

The drawing office, in conjunction with the tool room, decide the limits to within which size the components must be made, and if produced satisfactorily, any numbers of pairs will be interchangeable.

To ensure satisfactory gauging, a full system must be employed, which consists of checking every gauge by another. The workshop gauge must be checked to the inspection gauge, and the latter to the reference gauge.

Gauges should have their correct sizes at the standard temperature of 68°F (20°C), and standard reference gauges are adjusted to be correct at this temperature.

The three classes of gauges are :

(1) Workshop or production gauges, for workshop use to control the size of the component during manufacture.

(2) Inspection gauges, used for the final check on the finished component.

(3) Reference gauges, for checking and adjusting both workshop and inspection gauges.

Using the Gauges

When using gauges, the inspector must abide by certain rules and conditions. Gauges, owing to the highly important part they play in

production, and apart from their cost, must be treated and used with the greatest care. The following notes should always be borne in mind :

(*a*) " *Go gauges* " must not enter the component under pressure. Allow the gauge to " feel " its way freely without forcing.

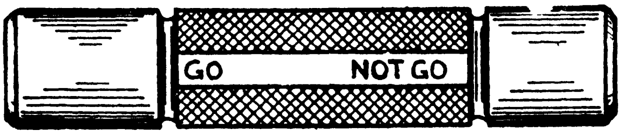


Fig. 72.—Double-ended plug gauge

(*b*) " *Not go* " *gauges* must *not* enter the component. Never try to force a " not go " gauge under any circumstances.

(*c*) *All gauges* must be checked periodically for wear, and be withdrawn at once should any discrepancy occur.

(*d*) *Gauging Conditions.*—A temperature of 68° F. has been established as the standard temperature condition for the application of limits applied to gauges and components.

The commonest type of limit gauges are the fixed size, plug and ring (classified as cylindrical), and the snap gauges.

Actual Size

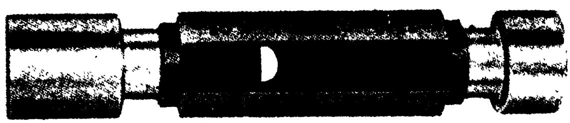


Fig. 73.—Small-plug gauge
(*By courtesy of The Newall Engineering Co., Ltd.*)

Plug Gauge (Fig. 72) is used to gauge hole sizes. One end is made to the low limit of the particular hole size to be gauged, plus a small wear allowance, and marked " go." The other end is made to the high limit, and marked " not go." Another method of distinguishing the " go " end from the " not go " is to make the " go " end the longer of the two.

In use, the " go " end should enter the hole, being made to the low limit size, but the " not go," being to the high limit size, must *not* enter. The plug gauge, as also does the ring gauge, leaves a certain amount of decision to the inspector. If the " go " plug enters the hole, then it is acceptable, but the amount of slackness which can be allowed rests with the inspector.

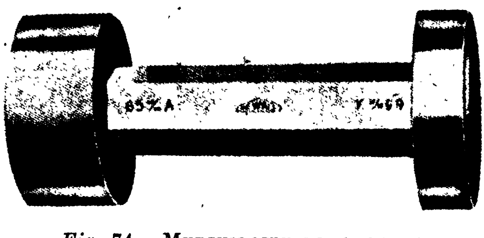


Fig. 74.—Medium-size plug gauge
(*By courtesy of The Newall Engineering Co., Ltd.*)

The plug gauge shown in Fig. 72 is made from the solid bar, but present-day practice tends to the making up of two-gauge

plugs on a separate handle. This method allows for replacement if wear should occur, or otherwise as necessary. In the larger sizes, where the sensitivity in handling may be adversely affected by excessive weight, the plugs are made of shell form, and secured to an aluminium handle. Illustrations of small, medium, and large plug gauges are given in Figs. 73, 74, and 75.

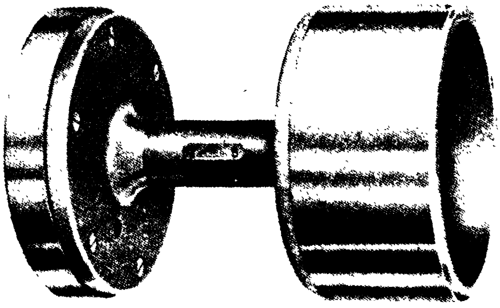


Fig. 75.—SHELL-FORM PLUG GAUGE
(*By courtesy of The Newall Engineering Co., Ltd.*)

When gauging blind holes, the " go " end of the gauge should be provided with an air vent, air groove, or air holes, according to the size of plug. If this provision is omitted, especially for close fits, it will not be possible to pass the gauge into the hole (Figs. 76 and 77).

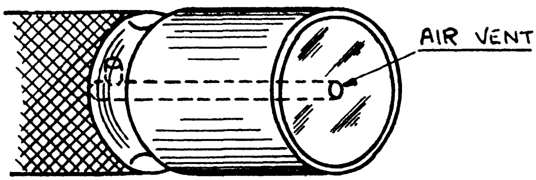


Fig. 76.—PLUG GAUGE WITH AIR VENT

Wear Allowance

This obviously increases the diameter on the " go " end of the plug gauge only. The reason for this allowance is that, should the gauge be made to the minimum diameter of the hole, as set by the tolerance, once wear has taken place the gauge would be undersize. The larger this allowance, the longer life will be given and gauge expense kept down. As against this, the larger wear allowance on the gauge will mean less tolerance for wear on the machine-shop tools.

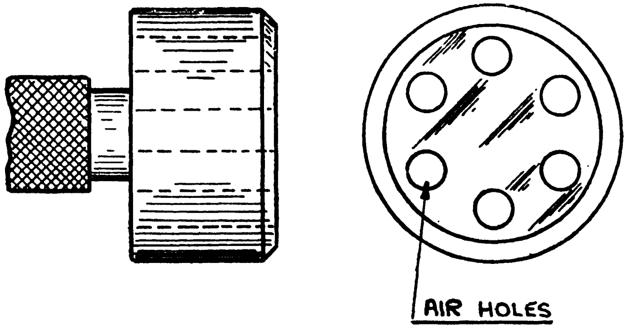


Fig. 77.—PLUG GAUGE WITH AIR HOLES

The "not go " end of the plug, if made to the high limit of the hole to be gauged, would theoretically suffice as it

would never enter the hole to necessitate wear allowance. However, for safety, a minus allowance is usually provided.

The wear allowance varies with the tolerance, and the amount necessary for standard types of plug gauges can be seen by referring to the table below.

Another method, approved by the Air Ministry, is to give a wear allowance of 10 per cent. of the tolerance.

TABLE OF WEAR ALLOWANCES FOR PLUG GAUGES

Tolerance on hole	*Wear allowance on gauge*	
	" Go " Plug.	" Not Go " Plug.
Up to ·0005″	Plus ·0001″	Size to minus ·0001″
Over ·0005″ and up to ·001″	,, ·0003″	,, ,, ·0003″
,, ·001″ ,, ·002″	,, ·0004″	,, ,, ·0004″
,, ·002″ ,, ·003″	,, ·0006″	,, ,, ·0006″
,, ·003″ ,, ·005″	,, ·0008″	,, ,, ·0008″
,, ·005″ ,, ·007″	,, ·0010″	,, ,, ·0010″
,, ·007″ ,, ·010″	,, ·0014″	,, ,, ·0014″
,, ·010″ ,, ·015″	,, ·0018″	,, ,, ·0018″
,, ·015″ ,, ·020″	,, ·0023″	,, ,, ·0023″
,, ·020″ ,, ·025″	,, ·003″	,, ,, ·003″

Manufacturing Tolerance

The manufacture of gauges is of a very highly skilled and specialised nature, and although a very high degree of accuracy is obtainable, it is impossible to produce a " Dead on " size without incurring excessive expense. To assist standardisation of very close limits for gauges, the National Physical Laboratory has compiled a specification which is given. It will be seen that, for cylindrical gauges, grades A and B are applicable, and for snap gauges, one simple grade is specified.

TOLERANCES FOR CYLINDRICAL PLUG, RING AND SNAP GAUGES

Diameter of gauge	*Plain cylindrical plug or ring*		*Snap gauges*
	Grade A	*Grade B*	*Standard grade*
Up to 1 in.	±0·00005 in.	±0·0001 in.	±0·0001 in.
From 1 in. to 2 in. ..	±0·0001 in.	±0·0002 in.	±0·0002 in.
From 2 in. to 4 in. ..	±0·00015 in.	±0·0003 in.	±0·0003 in.
From 4 in. to 6 in. ..	±0·0002 in.	±0·0004 in.	±0·0004 in.

See also B.S.I. Specification No. 969/1941

It will be observed that both wear allowance and manufacturing tolerance contribute to reduce the actual tolerance available to the

machine operator. It is therefore of vital necessity that these be kept to a minimum.

Chromium-plating

The adoption of chromium-plating gauges has given an increased life of approximately five times over that of the hardened gauge. Another advantageous consideration is that they are not subject to ordinary atmospheric conditions. Chromium-plating gives a higher surface energy, which means that the gauges are more slippery and therefore less subject to abrasion. Although the initial cost is only very little in excess of an ordinary hardened gauge, when taken over a period of use the actual cost is less.

Stellite and Tungsten Carbide Gauges

A still further life is obtained by the use of these materials. As experiments are still being carried out, the actual life extension cannot be definitely stated. However, available data shows that at least fourteen times the amount of extra life can be expected over the hardened gauge. Although, again, the cost will be increased, in this case by probably four to five times when taken over a period of use, the maintenance cost will be less.

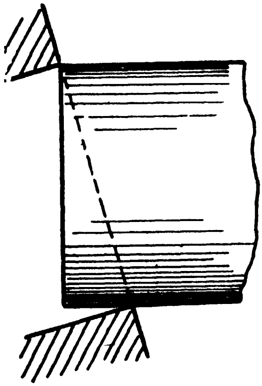


Fig. 78.—Ordinary plug "jammed" in hole

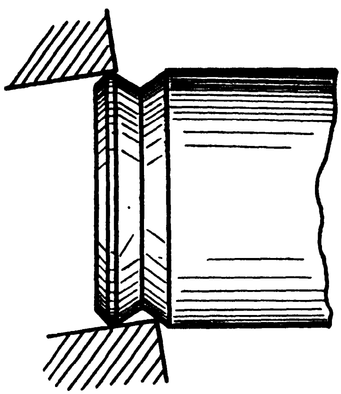


Fig. 79.—"Pilot" plug gauge

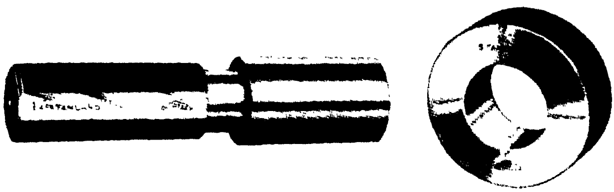
A definite advantage with regard to the long-life gauges is that wear allowance is reduced to the absolute minimum, thus increasing tool life.

The "Pilot" Plug Gauge (Figs. 78, 79)

There is always present a tendency for the ordinary plug gauge to jam under working conditions when gauging into a "size" and "size" hole. This accounts for a loss of $1\frac{1}{2}$ tenths extra tool wear. To obviate this, the Pilot Plug Gauge Co., Ltd., has introduced the "pilot" gauge, which reduces the drawing tolerance by two-tenths. This is a plug gauge, which has its end modified as shown in Fig. 79 to facilitate entry into the work.

A plug will jam because it is out of line with the hole, and jamming occurs across the hypotenuse of the triangle, shown dotted, Fig. 78.

If a gauge which has jammed is examined, a bright ring is observed, approximately $\frac{1}{16}$ in. from the entry end of the gauge. This is termed the " pressure ring," and the point where gauges are normally scrapped for undersize. The hypotenuse being longer than the base, a wedging effect occurs which firmly wedges the gauge into the component, so that it is necessary to use force to disengage the parts. Subsequent damage is caused to both hole and gauge.



Figs. 80 *and* 81.—STANDARD CYLINDRICAL AND RING GAUGES
(*By courtesy of The Newall Engineering Co., Ltd.*)

Pressure ring does not exist on the " pilot " gauge, as this position is taken by a groove provided as shown in Fig. 79. Should the gauge be out of square with the hole, it pivots about the "land," and the edge of the hole strikes the chamfer, thus piloting the gauge into line, and the correct entry position is taken up.

The " pilot " gauge is approved by the Air Ministry, Admiralty, Ministry of Supply, and the National Physical Laboratory.

Standard Cylindrical Gauges (Figs. 80 and 83)

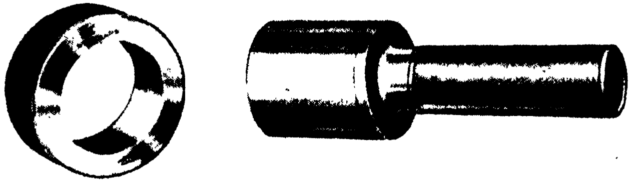
Whilst the use of limit gauges is recommended for production, the reference gauges are an essential part of the gauge equipment of tool rooms and inspection departments. These gauges can be used for checking sizes, setting micrometers and other measuring instruments. They should be produced within N.P.L. Grade " A " limits.

Ring Gauges (Figs. 81 and 82)

These are made for gauging shafts or round bars, spindles, etc. To distinguish the " go " ring from the " not go," the latter is usually made longer, or alternatively a groove is provided on the outside.

Snap, or Caliper Gauges (Figs. 84, 85 and 85A)

These gauges are flat and have small fixed gauging surfaces.



Figs. 82 *and* 83.—STANDARD RING AND CYLINDRICAL GAUGES
(*By courtesy of The Newall Engineering Co., Ltd.*)

Fig. 84 shows a common snap gauge which can

be readily made in any tool room from cast-steel plate, hardened and ground. This type can be made single- or double-ended as required.

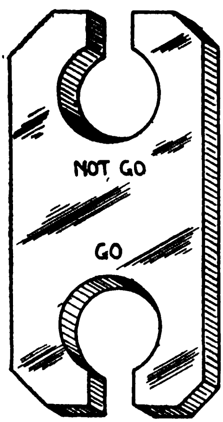


Fig. 84.—Common double-ended snap gauge

Figs. 85 and 85A give examples of single- and double-ended snap gauges made from case-hardened low-carbon steel stampings, the jaws being hardened, ground, and lapped to size for accuracy.

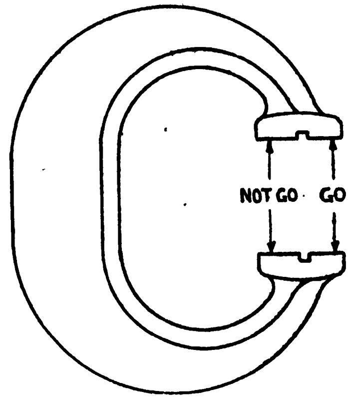


Fig. 85.—Single-ended snap gauge

Adjustable External Limit Gauges (Figs. 86 and 87)

The adjustable type of gauge was designed to overcome the necessity for the multiplicity of external limit gauges, as would otherwise be required to cover the installation of full gauging equipment.

This type of gauge can be employed on all classes of production, and being adjustable, is not affected by wear, as in the case of solid gauges.

The gauges have two fixed anvils on one jaw, and two movable anvils on the other jaw, thus forming two pairs of measuring faces, the front pair being the "go" and the rear pair the "not go" points. The adjusting screws are securely locked in position by means of cotters and nuts of special design.

By the length of travel of the adjusting screws, each gauge covers a range of sizes, and can be easily and quickly set up to the required diameter and limits within the gauge capacity.

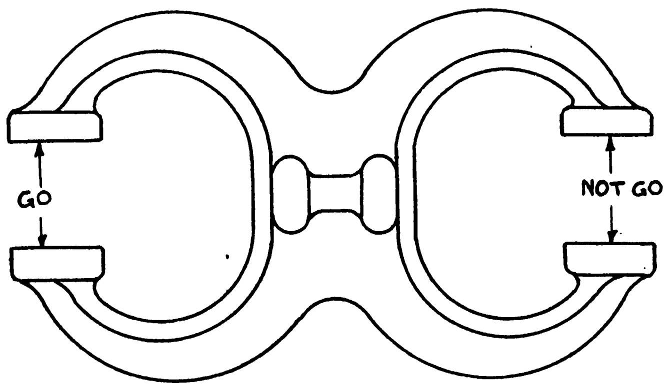


Fig. 85A.—Double-ended snap gauge

The usual range for this

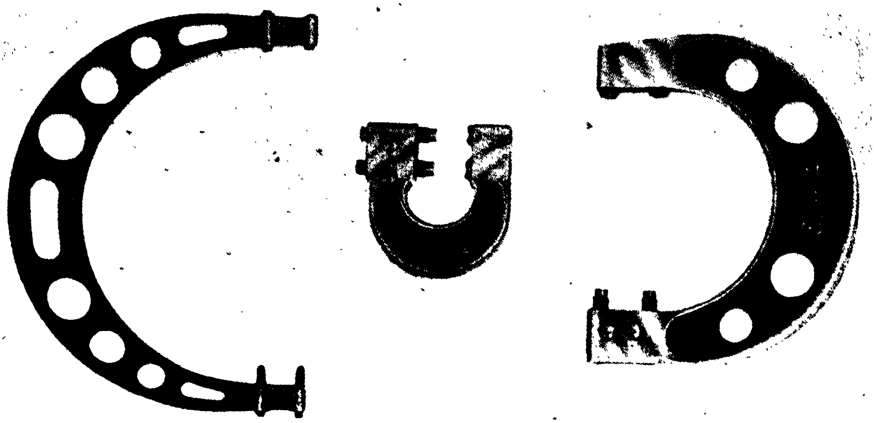


Fig. 86.—ADJUSTABLE EXTERNAL LIMIT GAUGE
(*By courtesy of The Newall Engineering Co., Ltd.*)

type of gauge is from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. (5 to 12 mm.) up to 29 in. to 30 in. (735 to 760 mm.). For sizes over 30 in., the frames are made of aluminium for lightness in handling, and give a range of 1 in. or 25 mm. on the adjusting screws.

Fig. 87.—ADJUSTABLE EXTERNAL LIMIT GAUGE
(*By courtesy of The Newall Engineering Co., Ltd.*)

Another pattern (Fig. 87) has come into favour, owing to the need for a superior quality and higher degree of precision gauge for modern repetition work.

The frame is made of decarbonised cast iron, of special section to ensure maintenance of truth and rigidity. On one jaw is carried an elongated anvil, of rectangular shape, hardened, ground, and lapped to a true plane surface, of area sufficient to cover the range of contact with the two circular-faced movable anvils which slide in the opposite jaw. The movable anvils are also hardened, ground, and non-rotating, their faces are lapped truly parallel with that of the fixed anvil, and their total capacity of adjustment, inwards or outwards, is $\frac{1}{4}$ in. They can be secured independently and positively to "go" and "not go" sizes at any desired point, by means of the locking

screws and within the range of the gauge. The slight chamfer on the front of all the gauging faces forms a lead for the component to be tested.

The range covered is ¼ in. to ½ in. (7 to 12 mm.) up to 5¾ in. to 6 in. (146 to 152 mm.).

The gauges can be supplied already set to specified sizes and limits and sealed by the makers, or where the equipment covers the necessary slips or blocks, can be set in the tool room.

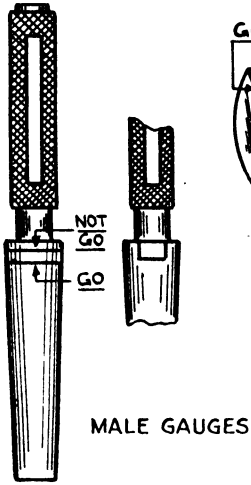


Fig. 88. Male taper gauge

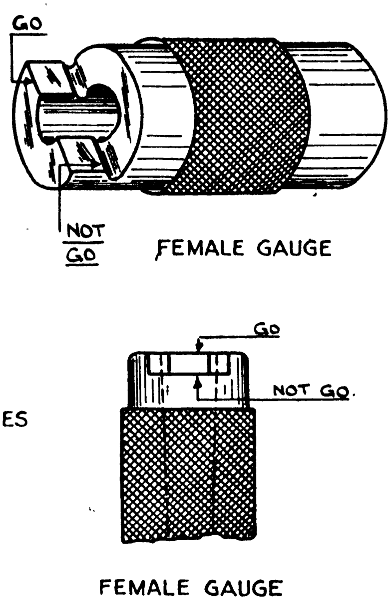


Fig. 90.—Female taper gauges

Taper Gauges
(Figs. 88, 89 and 90)

These gauges are employed for checking taper holes and corresponding exactness in various taper shanks. They are made of steel, hardened, ground, and lapped accurately to defined sizes. The method of making the check is to assemble the gauge and component and test for "rock." If no appreciable "rock" is apparent, a further check may be carried out by treating the taper shank with french chalk, or prussian blue, and assembling with the gauge. The "high spots" or contacting areas are shown up if the assembly is rotated. Apart from the diameter check, lines indicating "go" and "not go" are scribed on the male gauge, to check the taper longitudinally. Several methods of indicating "go" and "not go" have been adopted, some of which are shown in Figs. 88, 89 and 90.

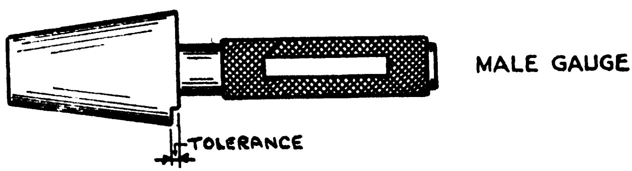


Fig. 89.—Male taper gauge—alternative type

Special-purpose Limit Gauges (Fig. 91)

These are often made, either by the manufacturers of the components themselves, or by gauge-making specialists, and designed to suit the special requirements. Examples are given in Fig. 91.

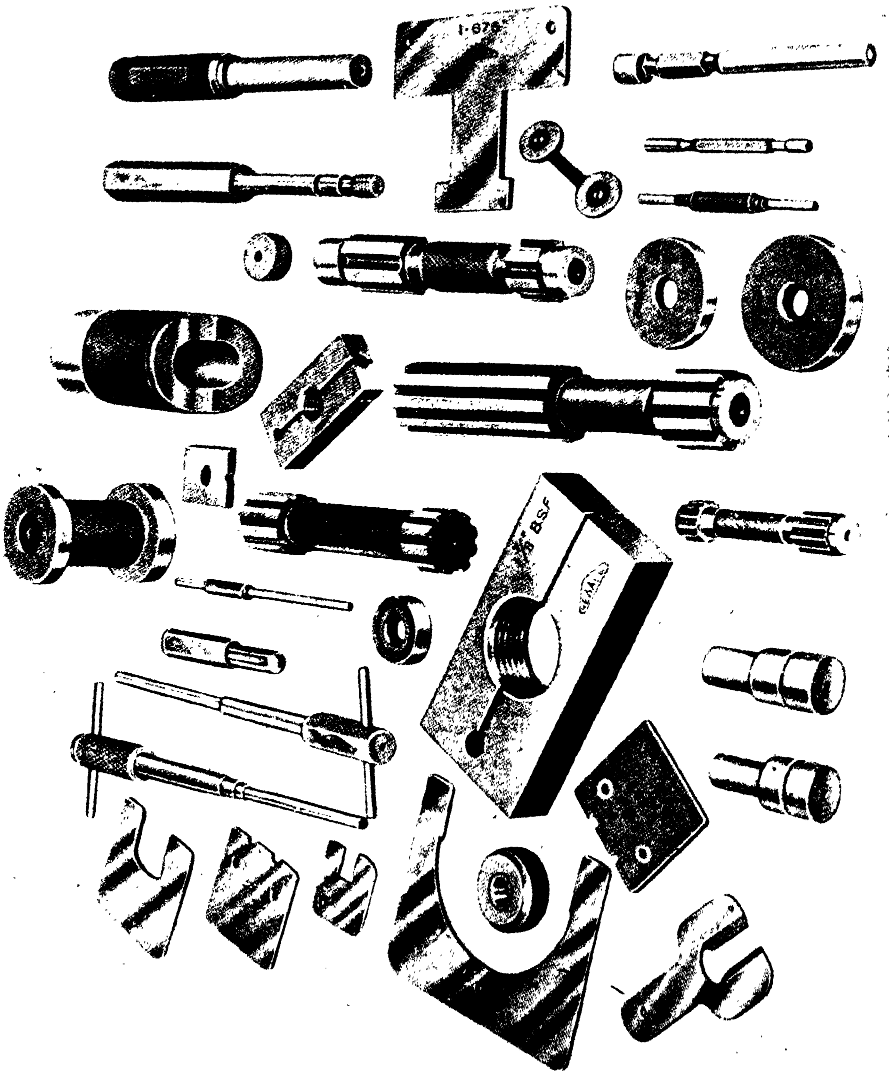


Fig. 91.—Special gauges
(*By courtesy of The Newall Engineering Co., Ltd.*)

Chapter IX

MEASURING SCREW THREADS

THE screw threads in common use are the "VEE," or "V," and the square threads. Among the former are British Standard Whitworth (B.S.W.), British Standard Fine (B.S.F.), British Standard Pipe (B.S.P.), and British Association (B.A.), these being the standards in this country. Also included in this category are those of America—

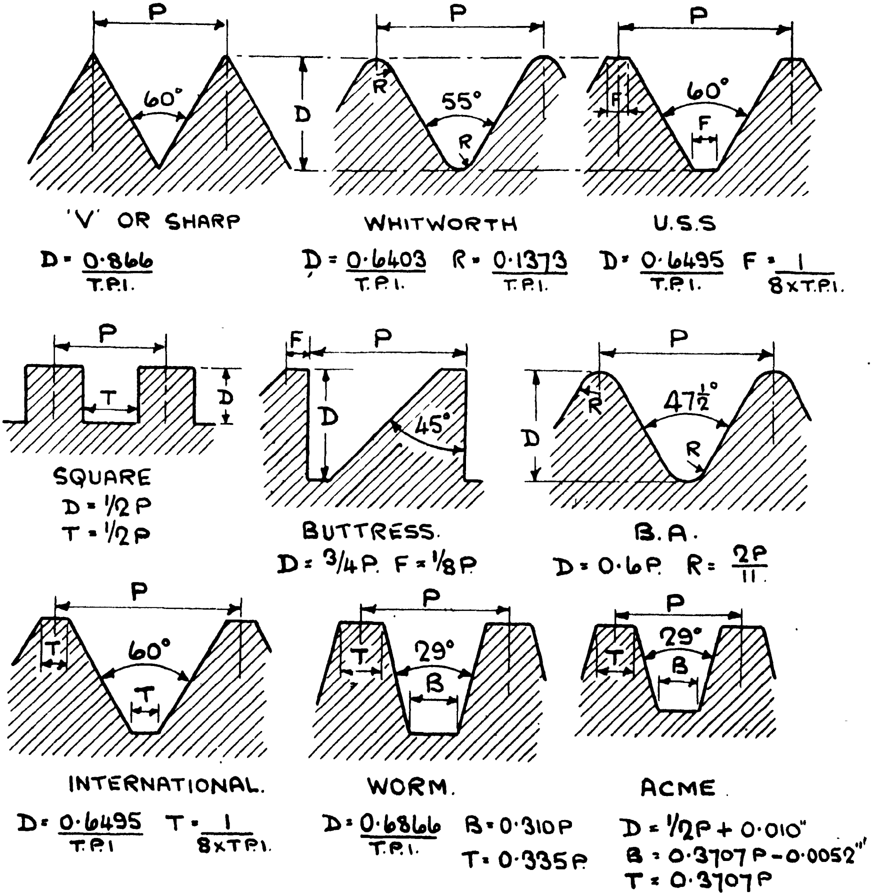


Fig. 92.—VARIOUS THREAD SECTIONS

United States Standard (U.S.S., or Sellers), Society of Automobile Engineers (S.A.E.), and the American Society of Mechanical Engineers (A.S.M.E.).

The International System Metric Thread (Système Internationale) is the recognised standard in most Continental countries.

Various thread sections are given in Fig. 92.

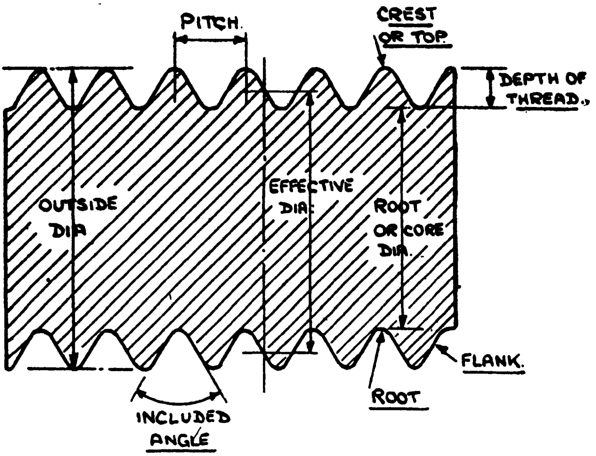


Fig. 93.—Screw thread terms

Terms used in connection with Screw Threads (Fig. 93)

Outside Diameter.—The diameter over the top or crest of the threads, i.e. the largest diameter.

Top or Crest.—The highest point of the section of the thread.

Pitch.—Pitch is the distance between successive crests of a screw thread. This applies either to single or multi-start threads. In the case of single threads, the pitch and lead are the same, but in the case of multi-start threads, the pitch differs from the lead. (See below).

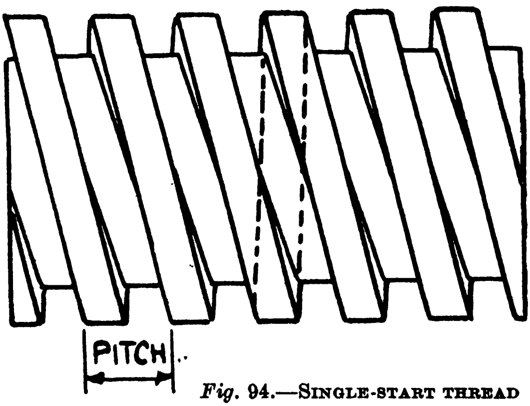


Fig. 94.—Single-start thread

Lead.—This term, which has already been referred to above, is used to indicate the distance of axial advance per revolution of a rotating pair. By this system the terms "pitch" and "lead" are quite distinct, as pitch is taken always, and only, as the distance from a point on a thread to the corresponding point on the next consecutive thread (Fig. 95).

Angle of Thread, or Included Angle.—The angle contained between the flanks or slope of a thread.

Depth of Thread.—The distance from the top of the thread to the root.

Root or Core Diameter.—The least diameter on the screw or nut.

Pitch or Effective Diameter.—The length of an imaginary line drawn at right angles to the axis of the screw, measured between the points where the line cuts the flanks of the thread. It is equal to overall diameter minus depth of thread.

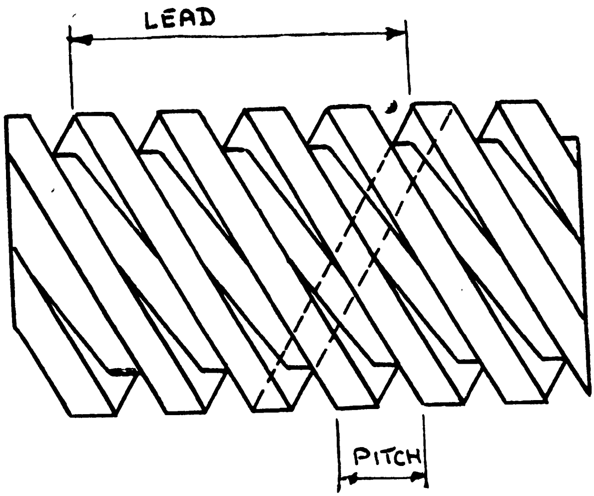


Fig. 95.—Four-start or multiple thread

Compound Effective Diameter.—The effective diameter, taken over a specified length of thread, and greater than the simple effective diameter by an amount due to error in the pitch.

Flank.—The straight part of the thread connecting root and crest.

To maintain a good standard of threads, the elements which must be controlled within predetermined tolerances are pitch, effective diameter, full diameter, root diameter and angle.

Regarding root and full (or outside) diameters, these are relatively unimportant, and it is merely necessary to ensure that they are not oversize.

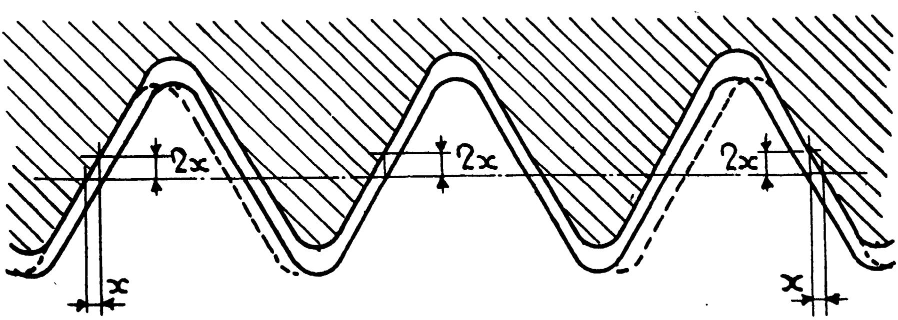


Fig. 96.—Showing how an error of x in the pitch increases the effective diameter by approximately $2x$

The standard of modern thread-forming tools is such that errors of the angle rarely occur, and a limit on the simple effective diameter ensures that, if error should be present, the strength of the thread is not impaired.

Screw-pitch Gauge (Fig. 97)

The pitch of a thread is conveniently determined by means of the screw-pitch gauge. Two sets of blades are provided, and on each blade are cut teeth of different pitch, corresponding to the standard thread profiles. These gauges are made in British, American, and Metric thread sizes. By placing these blades successively on the threads, until one blade will coincide, the pitch can be determined and read off the size inscribed on the blade. The free end of the blades is made narrower, to allow it to pass into restricted spaces, and both inside and outside threads can be gauged.

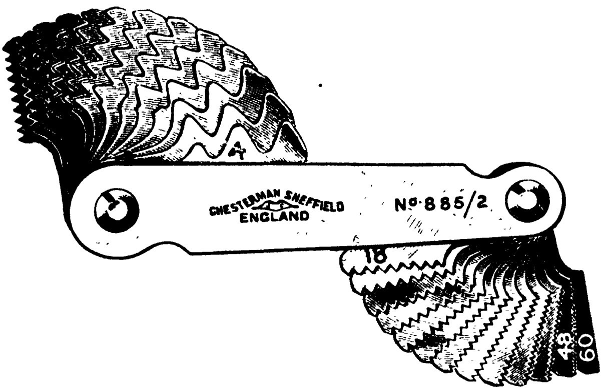


Fig. 97.—SCREW-PITCH GAUGE
(*By courtesy of James Chesterman & Co., Ltd.*)

When in use, the component being checked should be clean, and both gauge and component held to the light to facilitate gauging.

Plug-screw Gauges

Originally, "full-form" plug gauges were used to check female threads. These are accurately made, and conform as near as possible to the size and shape of the thread. An illustration (Fig. 98) shows a single-end "go" gauge of this type, and will serve as an approximate check, to ensure threaded parts screwing together and giving a reasonable fit. However, for strict interchangeability, the use of limit-screw gauges must be adopted.

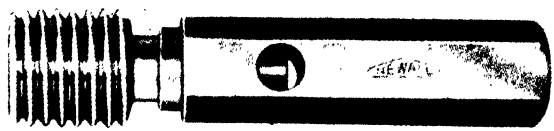


Fig. 98.—STANDARD PLUGS
(*By courtesy of The Newall Engineering Co., Ltd.*)

Plugs of the type shown in Fig. 99 carry a "full-form" "go," and an effective-diameter "not go," and are the most certain checks in the production of female threaded components. The effective diameter at

the "go" end is made to the minimum tolerance, and therefore the gauge should, at this end, freely enter the component. At the "not go" end, the effective diameter is made to the maximum tolerance, and the threads are truncated. The N.P.L. Limits of Tolerance for "not go" effective diameter screw gauges are given on page 87.

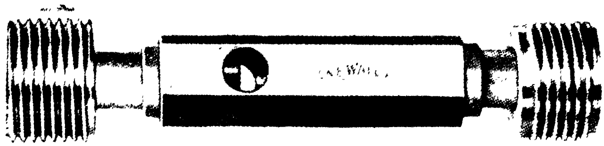


Fig. 99.—STANDARD AND EFFECTIVE "NOT GO" PLUGS
(*By courtesy of The Newall Engineering Co., Ltd.*)

The foregoing method of checking may be extended by the use of core (or root) diameter checks (Fig. 100). This gauge combines a standard threaded plug, with a plain plug for the "core diameter." The latter may be made to the maximum or "not go" size of the core, or alternatively, to the minimum or "go" size as required.

Ring Screw Gauges

For checking external or "male" threads, the ring screw gauge is very accurate, but the use of caliper screw gauges provides a very convenient alternative method.

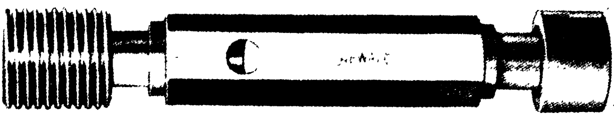


Fig. 100.—STANDARD AND PLAIN PLUGS
(*By courtesy of The Newall Engineering Co., Ltd.*)

Where expressly required, ring gauges can be obtained in pairs to specified limits, to serve the same purpose as the "go" and "not go" plug gauges. However, for general, commercial work, the employment of two separate gauges, where one would suffice, is discouraged.

Plug and ring gauges are hardened, ground, and lapped to size, and accurate within N.P.L. limits for either inspection or workshop gauges.

Checking Screw Gauges

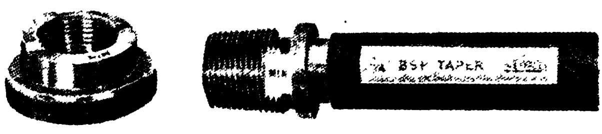


Fig. 101.—BRITISH STANDARD PIPE (B.S.P.) TAPER FORM RING AND PLUG

As with all inspection tools, screw gauges must be checked periodically. For this purpose, gauges are obtainable which are made to N.P.L. "Reference Limits." As an alternative, the gauges should be periodically submitted to an approved Air Ministry test house for test and report.

Roller Thread Gauges (Fig. 102)

The need for reliable and accurate control in the manufacture of screws, particularly the examination of all elements of threads simultaneously, has brought about the introduction and development of the roller thread gauge. There are a number of these gauges on the market, but a general description of the "Newall" Roller Thread Gauge, produced by The Newall Engineering Co., Ltd., Peterborough, will suffice the present need.

The frame is of horseshoe or caliper shape, and made from a special high-quality close-grained cast iron, thoroughly seasoned and chromium-plated. The ribbed truncated section of the bridge gives strength and rigidity.

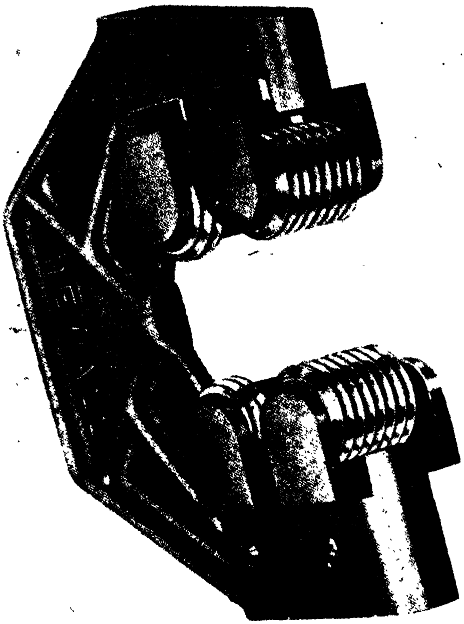


Fig. 102.—Roller thread gauge
(*By courtesy of The Newall Engineering Co., Ltd.*)

The anvils are of roller form, made of hardened tool steel, ground and lapped, both on their external threaded and internal diameters. The use of threaded roller anvils of like pitch, but helically opposed to that of the work being inspected, provides that there shall be no error when the helices of the gauging members and the work are engaged, whilst accurate registration on all elements of the threads is made simultaneously.

Simplicity of operation is assured by the lateral or endwise movement provided on the two upper or "go" roller anvils to allow for travel of the helix, this arrangement ensuring simple and rapid checking, as the work aligns itself automatically with the anvils, and therefore obviating the necessity for finding the correct position.

The complete gauge carries two pairs of roller anvils ; the front pair with "full form" of thread are the "go," or accepting members, the rear pair, having the "effective" diameter of thread only, are the "not go," or rejecting members. The amount of truncation from normal full diameter in respect of this latter pair of rollers is clearly marked on the gauge for setting purposes.

Independent adjustment is provided on both "go" and "not go" anvils, for setting to any limits within the capacity of the gauge, and actuates on the two upper anvils, the two lower anvils being stationary. To set the gauge to a specific size, the locknuts on the side of the frame are loosened, and the fork units raised or lowered by means of the adjusting screws at the top of the frame. The gauge can be set by means of either plain plugs or slip gauges, or with threaded setting plugs. Tightening the locknuts ensures positive and effective locking, and a button is attached to the frame, on which the size and limits can be marked.

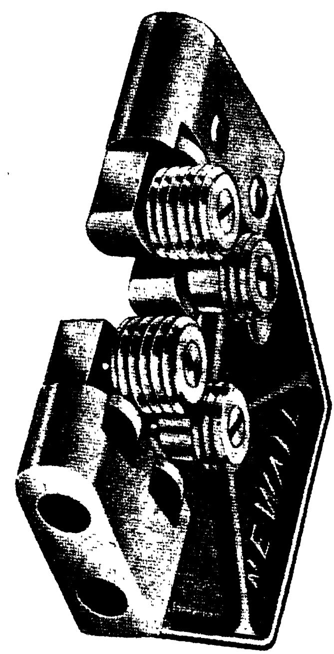


Fig. 103.—SHOULDER-TYPE ROLLER THREAD GAUGE

(*By courtesy of The Newall Engineering Co., Ltd.*)

The Standard Newall Roller Thread Gauge will check threads to within $\frac{1}{8}$ in. of a shoulder, but where it is essential that the anvils register close up to the shoulder, and without any allowance, as would be made for recesses, the "shoulder" type of gauge should be used.

A special feature of the Newall Roller Gauge is the "form construction" of the "not go" gauging members. For efficiency, a thread caliper should be rapid in action, and therefore, consideration must be given to details liable to cause incorrect inspection.

The styles of truncation in common use are as shown in Figs. 104A and B, the style 104A being mostly used. As the distance *A* is almost equal to *B*, it is obvious that an operator, unless careful, has an almost equal chance of "fouling" the work on the "full" diameter, as of correct engagement with the thread.

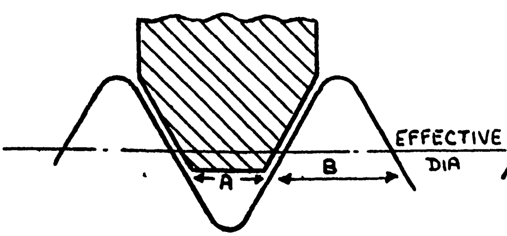


Fig. 104A

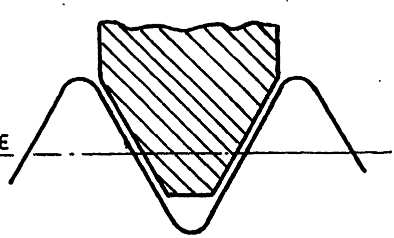


Fig. 104B

The style at *B* obviates this chance of error, but in doing so, leaves a danger of accepting certain types of thread malformation and wide angle.

The "Newall" truncation is shown in Fig. 105, and will be seen to give an easy and certain lead-in to the work, at the same time re 'ning the most advantageous check upon the "effective" diameter. The amount of truncation is always ·005 in.

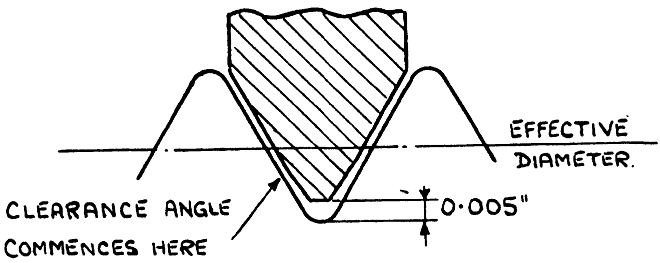


Fig. 105.—"NEWALL" TRUNCATION

The following formulæ give the correct slip, or setting-plug gauge sizes when setting by the tops of the gauging members.

"Go" setting size = Standard Effective Diameter — Depth of thread + or — Desired limit.

"Not go" setting size = Standard Effective Diameter — (Depth of thread — ·010 in.) + or — Desired limit.

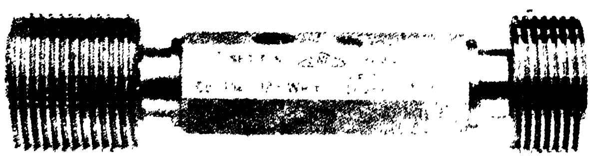


Fig. 106.—SETTING PLUG
(*By courtesy of The Newall Engineering Co., Ltd.*)

Thread Micrometers (Fig. 107)

For checking the pitch or effective diameter, thread micrometers are rapid and convenient in use. However, they have certain definite limitations.

In the case of the thread micrometer illustrated, the end of the spindle is conical and the anvil of V form. When measuring threads, only the angle of the point and the sides of the V anvil come into contact with the thread. Therefore, the pitch diameter,

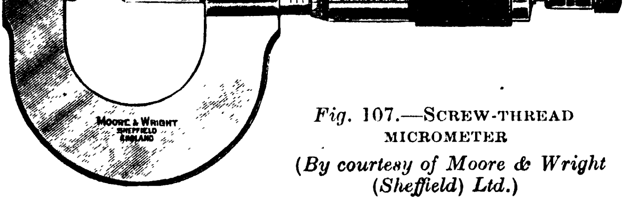


Fig. 107.—SCREW-THREAD MICROMETER
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

i.e. the full diameter less the depth of one thread, is the reading indicated.

To ensure correct reading, the micrometer should be set to a standard thread plug, and used for measuring threads having the same pitch and diameter as that of the plug. If not set in this manner, there is a slight amount of distortion, depending on the helix angle of the thread being measured.

When set to a plug, it will be observed that, on bringing the spindle and anvil together, the reading is not exactly at zero.

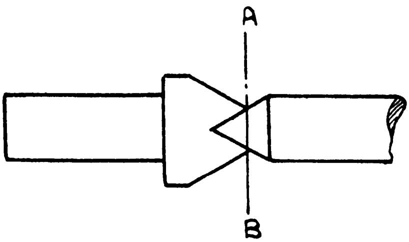


Fig. 108.—Zero position

In another type, the spindle is coned to the shape of the thread to be measured and the V-shaped anvil is free to rotate, allowing the pitch (or effective) diameter to be taken whatever the position of the frame, and counteracting the effect of the helix angle. The same spindle cone can be adapted for all pitches, but various anvils are necessary for the different thread pitches. When the spindle cone and anvil are in contact, the line AB (Fig. 108) corresponds to the zero position. The pitch diameter is equal to the full diameter, less the depth of one thread.

The depth of thread is found from the formula :

For Whitworth threads : $\frac{\cdot 64}{P}$

For International Metric and U.S. Standard threads : $\frac{\cdot 6495}{P}$

The micrometer reading for the pitch diameter for Whitworth threads is given by :

$$PD = F - \frac{\cdot 64}{P}$$

and for International Metric and U.S.S. threads :

$$PD = F - \frac{\cdot 6495}{P}$$

where PD = Pitch or effective diameter.
F = Full diameter.
P = Pitch.

Anvils are also obtainable having two or three grooves. (Fig. 109.)

One-wire System (Fig. 110)

When measuring by the wire method, the wire must be lapped to within ·0001 in. of the true cylindrical form to ensure accuracy.

The measurement of effective diameter can be taken by using a standard micrometer and one wire. The spindle of the micrometer bears against the crests (or tops) of the threads, and the anvil against the wire.

Assuming the effective diameter is correct, and the micrometer reading is M, then the formula for a Whitworth thread is :

$$M = 1{\cdot}583d - \frac{{\cdot}8004}{\text{T.P.I.}} + \text{Nominal Outside Diameter},$$

where d = diameter of wire.
T.P.I. = No. of threads per inch.

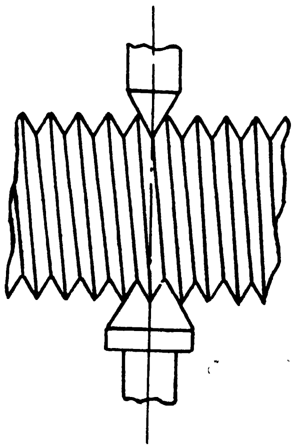


Fig. 109.—Grooved anvil

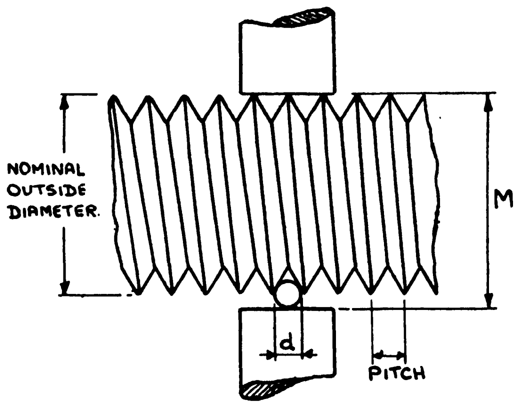


Fig. 110.—One-wire system

If the screw should be oversize, one-half of the amount of oversize must be added to M. Again, should the screw be undersize, one-half the amount of undersize must be deducted from M.

Three-wire System (Fig. 110A)

For checking to a fine degree of accuracy, the three-wire system should be employed. The three wires are of such diameter that, when resting between two threads, the wire touches them at points separated by half the pitch. Two wires are placed in adjacent thread spaces on one side of the screw, and the third wire on the opposite side, midway between the first two wires. The micrometer measurement then checks the diameter over the wires, and therefore the diameter of the imaginary cylinder containing their points of contact with the screw. This is the same as the effective diameter if the screw is correct.

The following formula will give the value of M, to obtain the correct reading :

$$M = d - xp + yd_2$$

where M = micrometer reading (or diameter over wires).
d = outside diameter of threads (over tops).
p = pitch of thread.
d_2 = diameter of wires.

The values for x and y are :

For B.S.W. threads $x = 1{\cdot}6008$; $y = 3{\cdot}1657$
For B.A. threads $x = 1{\cdot}7363$; $y = 3{\cdot}4829$
For U.S. threads $x = 1{\cdot}5156$; $y = 3{\cdot}000$

The size of the wires is usually about two-thirds of the pitch, and should serve for at least three different threads. Generally, the wires are finished to exact sizes, as ·030 in., ·040 in., etc., and for B.S.W. threads must not exceed ·840 p, or be smaller than ·506p.

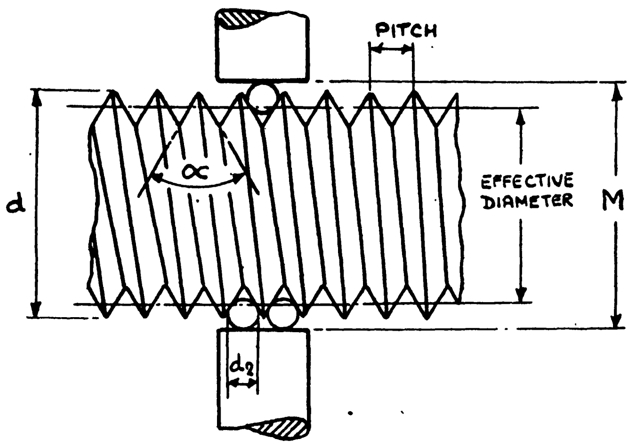


Fig. 110A.—THREE-WIRE SYSTEM

The effective diameter can be found from the following formula, where the value of C for Whitworth threads varies from ·0001 in. to ·0002 in. (see Fig. 110A).*

$$\text{Effective diameter} = M + \frac{P}{2 \tan \frac{\alpha}{2}} - d - \frac{d}{\sin \frac{\alpha}{2}} - C$$

The Two Wire System

If a floating micrometer machine is available the two wire system of measurement should be used. A full description of this machine and the method of using it will be found in a brochure entitled "Notes on Screw Gauges," compiled by the Metrology Department of the National Physical Laboratory and obtainable from H.M. Stationery Office, price 4/6.

(*) C is the correction term compensating for the obliquity of the wires and its actual value can be obtained from specially prepared charts issued by the Société Genevoise d'instruments de Physique, Geneva.

the reading which the micrometer should register, are supplied for each thread standard. The wires are interchangeable, and the mounting adapted to suit the type of threads to be checked.

Wickman Adjustable Thread Gauge (Fig. 111)

The four anvils are adjustable, and are complete forms of the thread, and no oversize element of the thread can pass them. They are of sufficient width to form a check over the pitch in the required length of screw engagement.

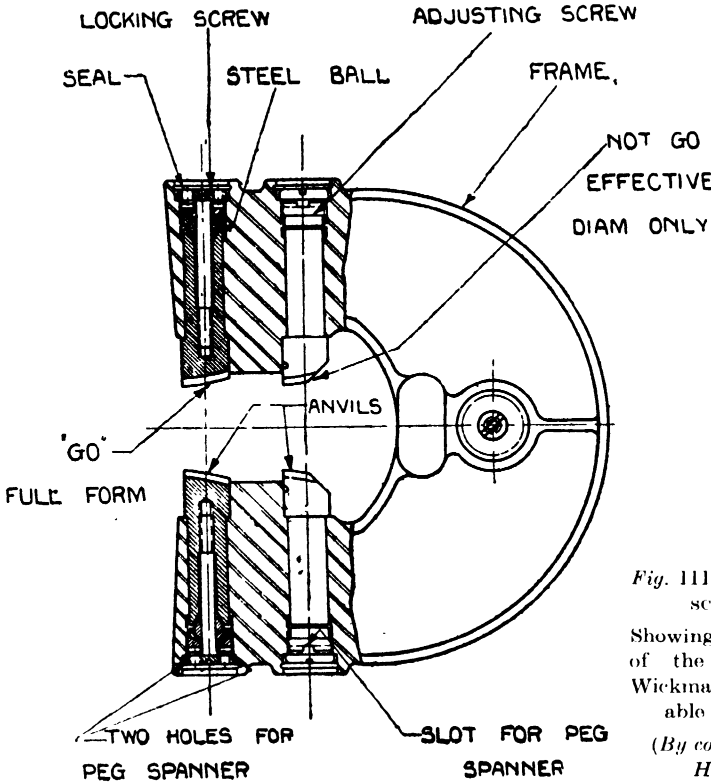


Fig. 111.—THE WICKMAN SCREW GAUGE

Showing the construction of the anvils of the Wickman Patent Adjustable Caliper Gauge

(*By courtesy of Alfred Herbert, Ltd.*)

The front or "go" pair of anvils are provided with a "full" form of thread. The "not go" pair of anvils at the rear are made to check the effective diameter only, and have truncated threads; also, by gauging one thread only, pitch error does not interfere with the correct functioning. The part threads on these anvils are arranged at the ends, so that gauging increases the effective diameter of the screws. To pass the "go" anvils, the screw thread must be small enough to compensate for pitch error. Should the pitch error be too great, then to pass the "go" anvils the

effective diameter must be too small, and the screw may pass the "not go" anvils and become a reject.

The gauge therefore checks that on the front anvils no element of the thread is oversize, and on the rear anvils that the simple effective diameter is not undersize.

The threads on the anvils are "form relieved" in order that they do not interfere with the helix angle of either right- or left-handed screws, both of which can be checked in the same gauge.

Wear is taken up by grinding the faces of the anvils and resetting to reference plugs.

N.P.L. LIMITS OF TOLERANCE FOR "NOT GO" EFFECTIVE DIAMETER SCREW GAUGES

CLASS	PLUGS				RINGS			
	Up to and including 1·5" and B A Screws Nos 0–15	Above 1·5" and up to 3"	Above 3" and up to 6"	Over 6"	Up to and including 1·5" and B A Screws Nos 0–15	Above 1·5" and up to 3"	Above 3" and up to 6"	Over 6"
	In	In	In	In.	In.	In.	In.	In.
INSPECTION	+0·0003	+0·0005	+0·0007	+0·0010	+0·0000	+0·0000	+0·0000	+0·0000
	−0·0000	−0·0000	−0·0000	−0·0000	−0·0003	−0·0005	−0·0007	−0·0010
WORKSHOP	+0·0000	+0·0000	+0·0000	+0·0000	+0·0003	+0·0005	+0·0007	+0·0010
	−0·0003	−0·0005	−0·0007	0·0010	−0·0000	−0·0000	−0·0000	−0·0000

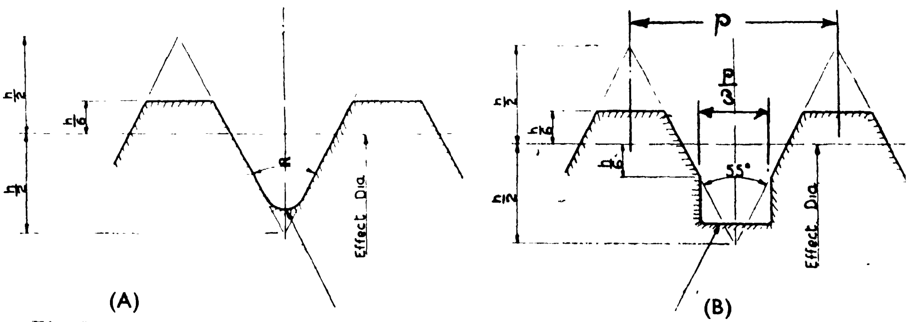


Fig. 112.—FORM OF THREAD FOR "NOT GO" EFFECTIVE DIAMETER SCREW GAUGES.
(*A*) For Whitworth threads finer than 20 T.P.I. $a=55°$. For B.A. threads $a=47\frac{1}{2}°$.
(*B*) For Whitworth threads having 20 T.P.I. and coarser.

Root diameter must clear crest diameter of minimum nut or maximum bolt. Form of relief not material except that it should restrict radial length of flanks between pitch line and roots to h/6.

Chapter X

ANGULAR MEASURING INSTRUMENTS

THE simplest tool for checking angular measurement is the bevel gauge (Fig. 113). A disadvantage with this tool is that the reading cannot be taken direct. Whether the gauge is set to the component or to a predetermined angle, the measurement has to be taken either by means of a plain protractor or sine bar.

A modification to the simple bevel gauge is the combination bevel (Fig. 114). A split blade is hinged on the stock, and an auxiliary slotted blade clamped on the split blade. Both split and auxiliary blades are adjustable to any angle.

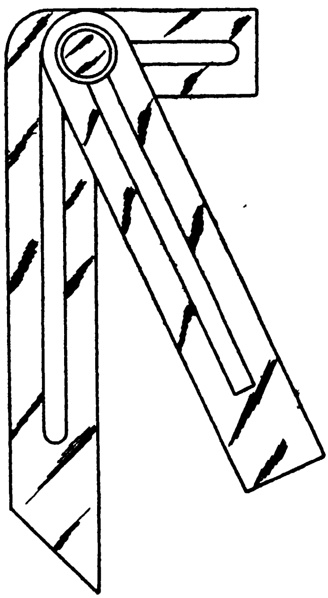


Fig. 113.—BEVEL GAUGE

The Universal Bevel Protractor (Fig. 115)

Many varieties of protractors are available, of which the example illustrated is typical. The protractor is a graduated disc with fixed blade and adjustable stock, giving angular measurement to within the limits of 5 mins., or $\frac{1}{12}°$. The disc is graduated in degrees over an arc of 180°, reading 0° to 90° each way, and rotates the entire circle on its centre stud. One side of the stock is flat, allowing the gauge to be laid flat upon the work. Any angle can be measured or set out, by setting the stock at that particular angle on the disc. The blade is clamped by means of an eccentric stud against the end of the disc, and can slide forwards and backwards over its full length, or can turn through any angle around the circle, and be clamped firmly in any position. Two verniers are fixed on the disc, and so arranged in relation to the graduations on the disc, or main scale, that the protractor can be read by vernier in any position to within the limits previously stated.

The vernier is graduated to read to $\frac{1}{12}°$ or 5 mins., and each space on the vernier is 5 mins. shorter than two spaces on the main scale. When

the zero line on the vernier coincides with the zero line on the main scale the edges of the base and bláde of the protractor are parallel. When the swivel head is rotated so that the line on the vernier, next to the zero line, coincides with the line next but one to zero on the main scale, the included angle of base and blade has been changed $\frac{1}{12}^\circ$ or 5 mins.

To read the Universal Bevel Protractor

First read off directly from the main scale the number of whole degrees between 0 and the 0 on the vernier scale. Next, count in the same

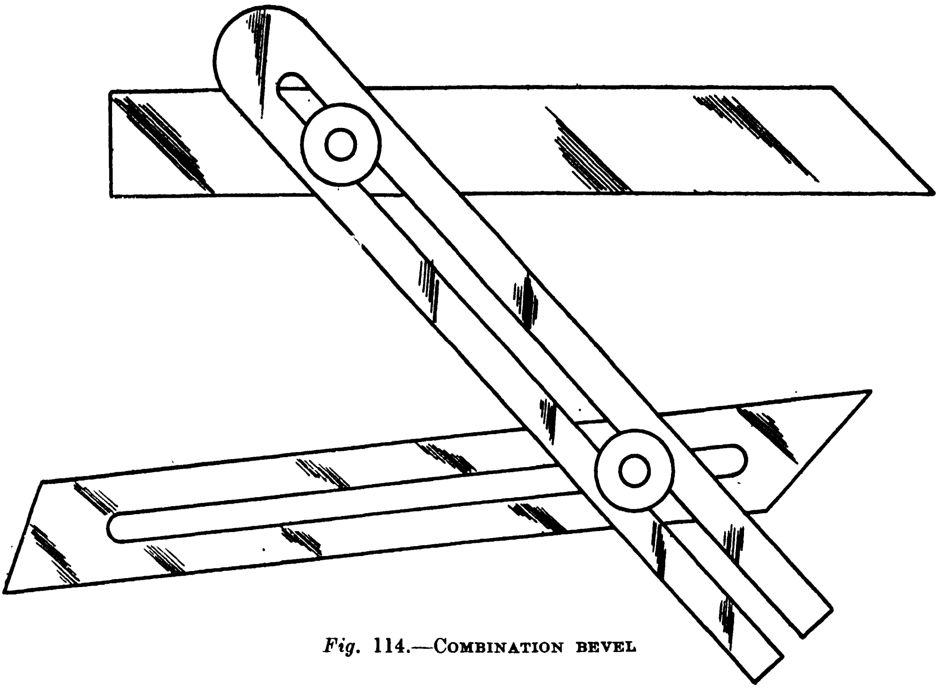


Fig. 114.—COMBINATION BEVEL

direction the number of spaces from zero of the vernier scale to a line coinciding with a line on the main scale, multiply this number by 5, and the product will be the number of minutes to be added to the whole number of degrees. An example is given in Fig. 116.

Some applications of the use of the protractor are given in Fig. 117.

The Combination Set (Fig. 118)

The combination set is a combination of all the essential features of the try-square, mitre-square, and centre-square. For using as a try-

square, the blade is inserted into the head *A*, and secured firmly with the thumbscrew. The head is adjustable along the length of the blade, and as the latter is graduated in the same manner as a rule (the usual ranges being $\frac{1}{8}$ in., $\frac{1}{16}$ in., $\frac{1}{32}$ in., and $\frac{1}{64}$ in.; $\frac{1}{16}$ in., $\frac{1}{32}$ in., $\frac{1}{64}$ in., and $\frac{1}{100}$ in.; or one side $\frac{1}{2}$ mm. and $\frac{1}{32}$ in., and the other in mm. and $\frac{1}{64}$ in.), the square can be used in the same manner as a depth gauge. A scriber is concealed in the head, and can be removed for marking-off purposes (*B*).

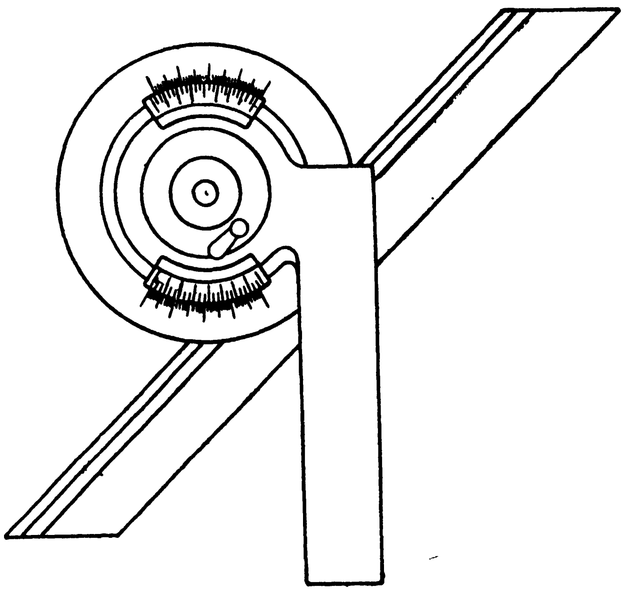
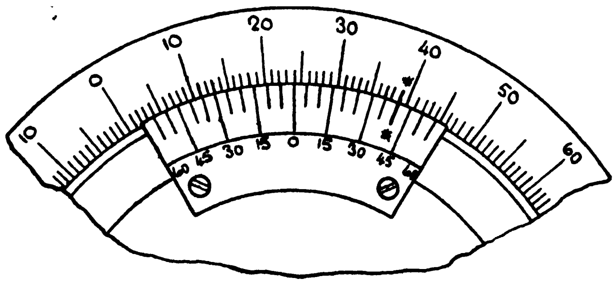


Fig. 115.—The universal bevel protractor

When using the square for marking-off purposes, the blade is held vertically, with the head resting on the surface plate. To ensure stability, a spring clip is available, which fits over the head and rests on the surface plate. One edge of the head is machined to 45°, facilitating setting out or measuring this angle.

The centre-square *C* is used for setting out the centres of round or square bars. The blade is arranged in the head so that the angle between the machined faces is bisected, and it is therefore only necessary to scribe two lines on the end of the bar to accurately ascertain its centre. To ensure this



READING — WHOLE DEGREES = 23
NUMBER OF SPACES FROM VERNIER ZERO = 8
8 × 5 = 40 MINUTES
PROTRACTION READING = 23 DEGREES 40 MINUTES

Fig. 116.—Example of protractor reading

accuracy, the bar must be concentric and free from outside obstructions.
The protractor head *D* is used for setting the blade to any required angle, and is clamped in position by means of the knurled screw. The

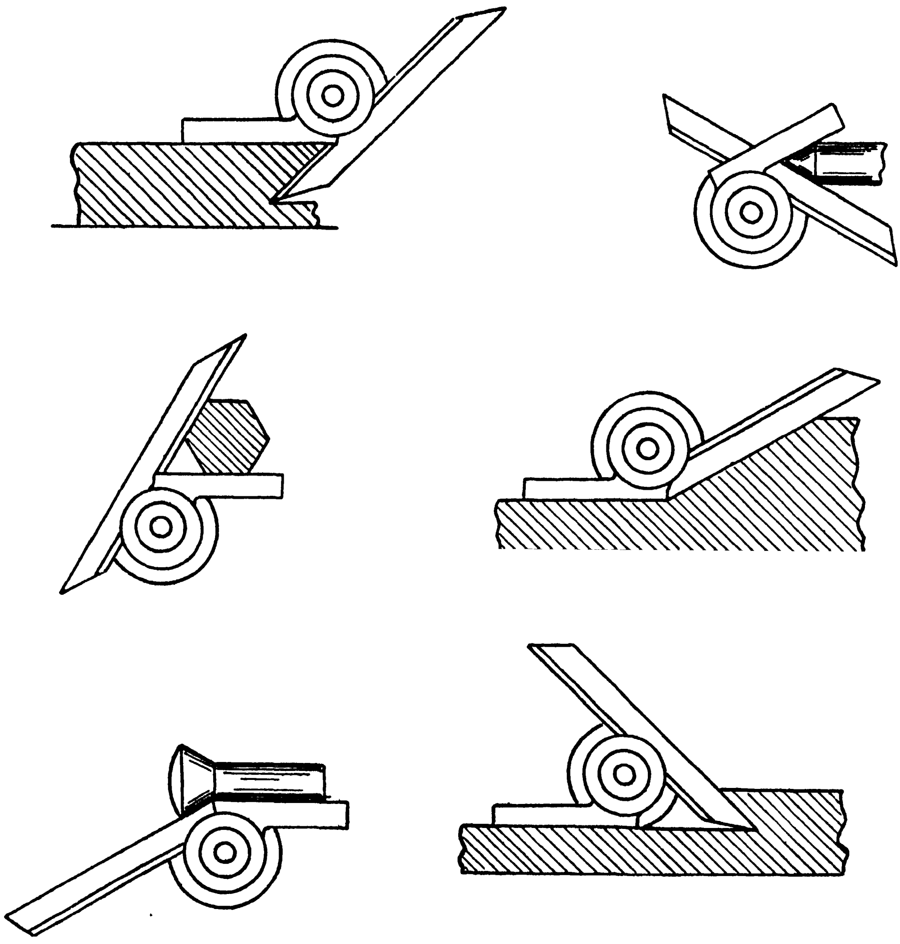


Fig. 117.—SOME APPLICATIONS OF THE UNIVERSAL BEVEL PROTRACTOR

revolving turret of the protractor is graduated from zero to 180°, and can be read in both directions. The scale divisions are of 1°, but measurement can easily be taken to ½°, which is usually of sufficient accuracy for average work.

To set the work plumb, a spirit level is often incorporated in both head and protractor turret. Applications of the combination set are given in Fig. 119.

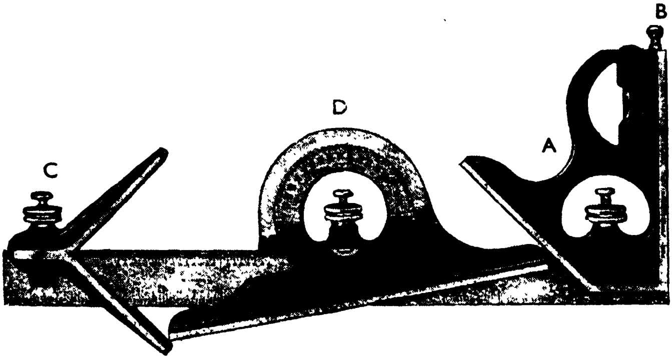


Fig. 118.—COMBINATION SET
(*By courtesy of Moore & Wright (Sheffield) Ltd.*)

Spirit Levels

There are many types of spirit levels available for setting up work, such as castings, for checking. Plain block levels are available having either a flat or "Vee" base,

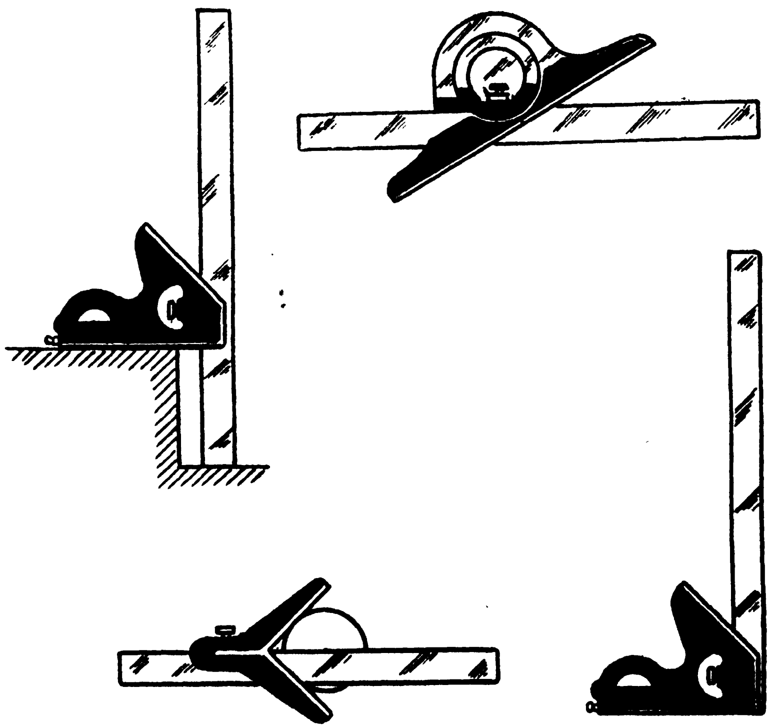


Fig. 119.—SOME APPLICATIONS OF THE COMBINATION SET

or combined flat and " Vee " base. A typical example is shown in Fig. 120, having a " Vee " bearing surface of 120° combined with a flat surface. This type can be used for mounting on shafts, test bars, etc.

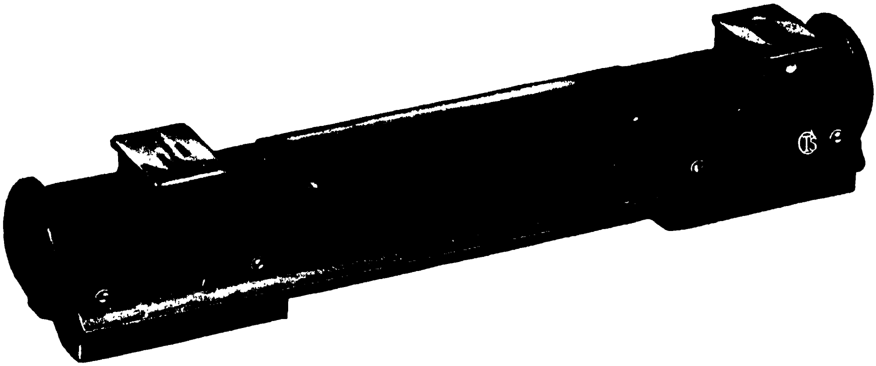


Fig. 120.—BLOCK LEVEL
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

The effect of heat from the hands is minimised by surrounding the spirit level with a shield of insulating material.

Adjustable Level (Fig. 121)

The body of this level is made of best cast iron, and so designed that

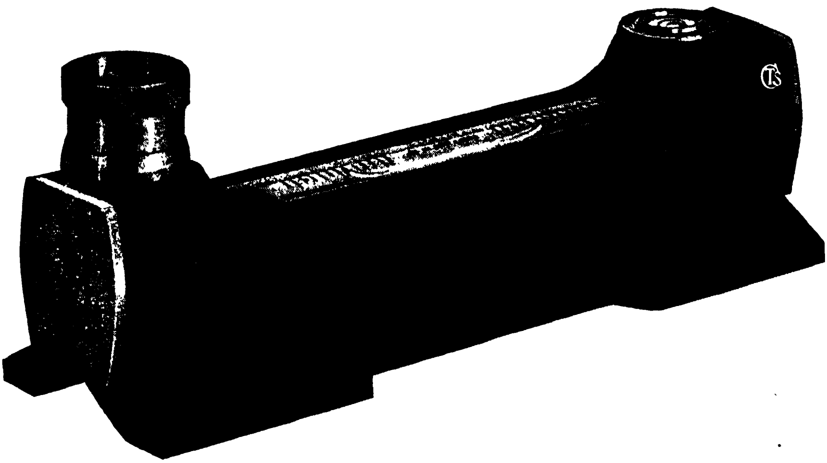


Fig. 121.—ADJUSTABLE LEVEL
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

it will not readily yield to bending or twisting stresses. The bearing surfaces are the combined 120° " Vee " and flat.

This level, in addition to establishing the true horizontal, also measures

the inclination of shafts or surfaces within the range of adjustment, viz. 3° elevation and 2° depression.

The gradient is expressed in thousandths of an inch per foot, and can be easily read by means of the divided drum mounted on the gradienter screw, and the scale on the end plate, which also carries a degree scale reading to 10 mins. direct.

One division of the drum represents a gradient of ·001 in. in 12 in. (= 1 in 12,000), or an angle of 17·16 secs. of arc, and corresponds to a movement of the bubble of 1 division, i.e. ·1 in.

A small circular spirit level in a brass mount is fitted to facilitate cross levelling.

The length is 8 in., and overall width of striding surface 2·5 in.

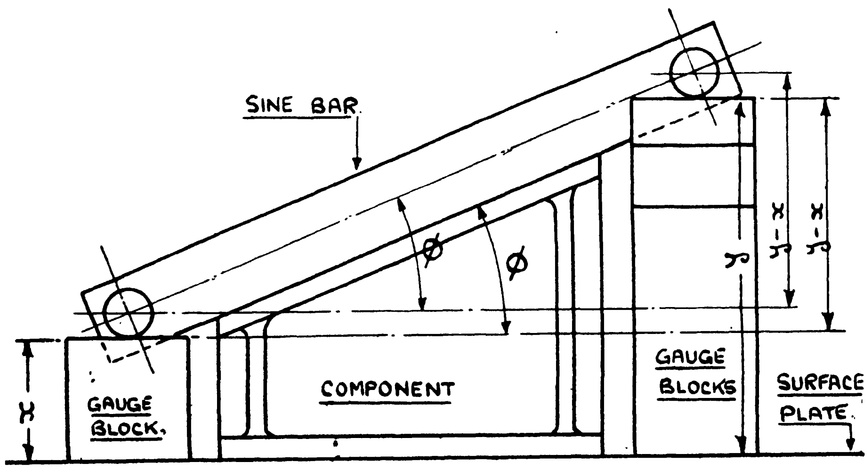


Fig. 122.—THE SINE BAR IN USE

The Sine Bar

The principle of the sine bar is based on the trigonometrical ratio, $\frac{\text{Perpendicular}}{\text{Hypotenuse}}$ = Sine (as given in Chapter V).

The hypotenuse is represented by the sine bar, which is a hardened and ground bar of known length, the gauging points usually being 5 in. or 10 in. between their centres. The hypotenuse and perpendicular length can be ascertained to an accuracy of $\frac{1}{10000}$ in., and therefore the sine bar gives accurate measurement of angles up to 45°. After this angle, the steepness of the slope begins to affect this method of angular measurement, and error begins to appear.

The simplest form of sine bar has two projecting hardened-steel pins, set at accurate centres of either 5 or 10 in., and can be set up by using

gauge blocks as shown in Fig. 122. By subtracting the height of the gauge blocks X from the height of the blocks Y, the perpendicular is obtained, and from this, according to the centres of the steel pins, the angle ϕ can be obtained.

Thus : $\text{sine}\ \phi = \dfrac{Y - X}{5}$ or $\dfrac{Y - X}{10}$

Supposing the height $X = 1{\cdot}0000$ in., this can be set up by one gauge block of 1·0000 in., and if $Y = 2{\cdot}655$ in., this can be made up by using blocks 2·0000 in., ·4000 in., ·1450 in. and ·1100 in., giving the required 2·655 in.

$$\text{Therefore : } \phi = \text{sine}\ \frac{2{\cdot}655\ \text{in.} - 1{\cdot}0000\ \text{in.}}{10} = \frac{1{\cdot}655}{10}$$
$$= \text{sine}\ {\cdot}1655 = 9^\circ\text{-}30'.$$

Should it be desired to set the sine bar to a known angle, it is only necessary to find one dimension, viz. the perpendicular height (as shown in Chapter V), the sine bar centres already being known.

For example, if the lower edge of one pin is set to the base line of the triangle, then the perpendicular height for an angle of 47° is, using a 10-in. bar, sine $47^\circ \times 10$, and since sine $47^\circ = {\cdot}6820$ the perpendicular height is $\cdot6820 \times 10 = 6{\cdot}820$ in.

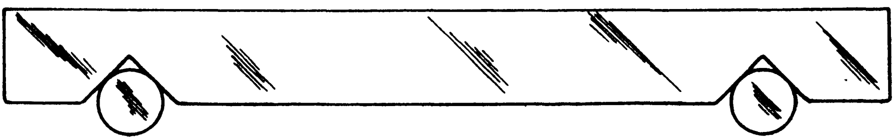


Fig. 123. THE PRATT AND WHITNEY SINE BAR

If a 5-in. bar is used, the perpendicular height will be sine $47^\circ \times 5 = {\cdot}6820 \times 5 = 3{\cdot}410$ in. (which is exactly half of the previous length).

Checking back again, with the bar size 5 in., and the perpendicular height now known to be 3·410 in.,

$$\text{sine}\ \phi = \frac{3{\cdot}410}{5} = {\cdot}6820, \text{ and sine } {\cdot}6820 = 47^\circ.$$

The Pratt and Whitney sine bar is shown in Fig. 123, and has two right-angle " Vee " notches in the bottom face, the apexes of these being exactly 5-in. or 10-in. centres. The notches seat on two accurately cylindrical rollers.

To facilitate handling, and ensure rigidity during gauging, the sine bar can be mounted on an angle plate. Fig. 124 clearly indicates the method of set-up.

Another useful sine bar is the Taft-Peirce (Fig. 125), which is entirely self-contained. The bar is of angular form, similar to a try-square, and is pivoted on a stud in the angle, and is adjustable vertically in the slot on the upright member. The lower edge of the bar and the top of the

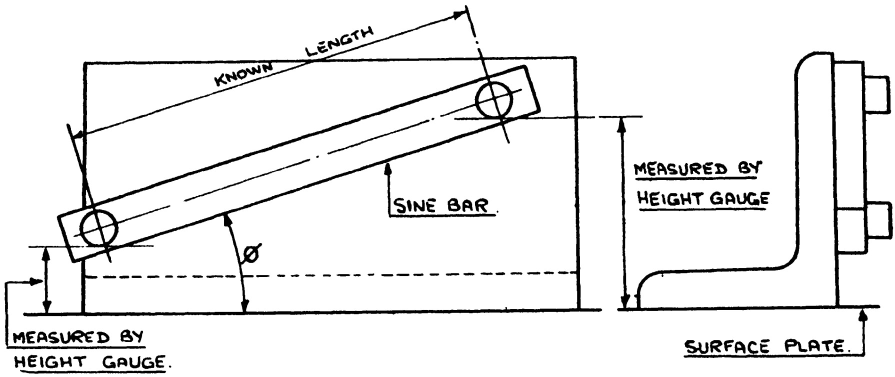


Fig. 124.—SINE BAR MOUNTED ON ANGLE PLATE

straightedge (which is set in the base) are used for checking angles. The straightedge forms a datum from which the vertical distances are measured. The centres of the pins are 5 in.

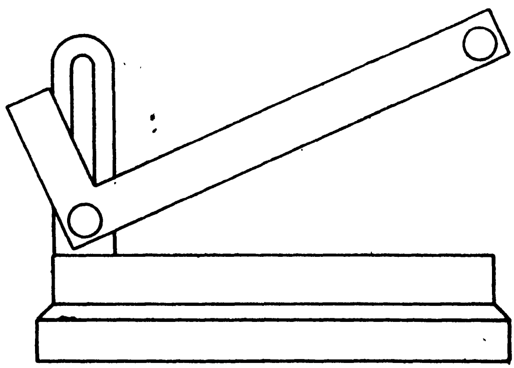


Fig. 125.—THE TAFT-PEIRCE SINE BAR

Johanssen Angle Gauges (Figs. 126A–D)

The set is made up of eighty-five hardened-steel, flat, narrow plates. These gauges cover three ranges, the first being from 10° to 11°, there being four angles to each plate, and increasing by 1 min. ; the next range

covers 90° to 91°, increasing by 1 min., but the plates having only two angles to each. To complete the set, a range of plates is included covering whole-degree angles from 11° to 90°, increasing by single degrees. The

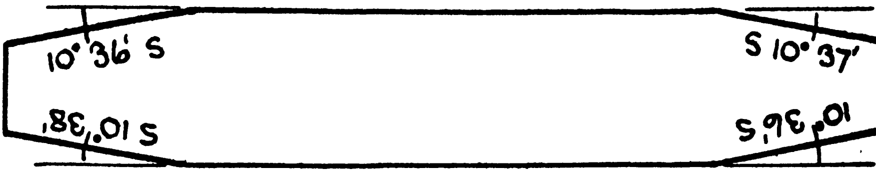


Fig. 126A.—JOHANSSEN ANGLE GAUGE—FIRST RANGE

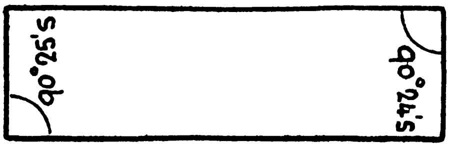


Fig. 126B.—JOHANSSEN ANGLE GAUGE—SECOND RANGE

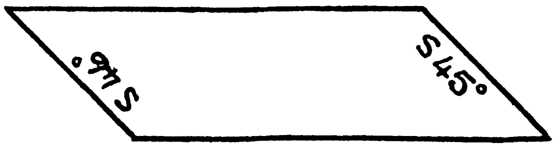


Fig. 126C.—JOHANSSEN ANGLE GAUGE—THIRD RANGE

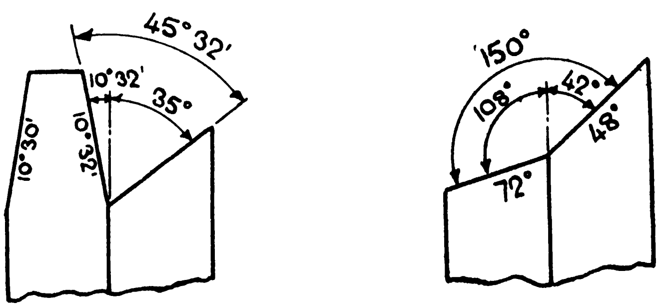


Fig. 126D.—METHOD OF COMBINING JOHANSSEN ANGLE GAUGES

plates can be built up to give any required angle, and the total range covered in this way is from 10° to 350°, increasing by minutes.

Angle-block Gauges (Fig. 127)

The angle-block gauges have largely been developed by the National Physical Laboratory, and are now being introduced into the engineering industry.

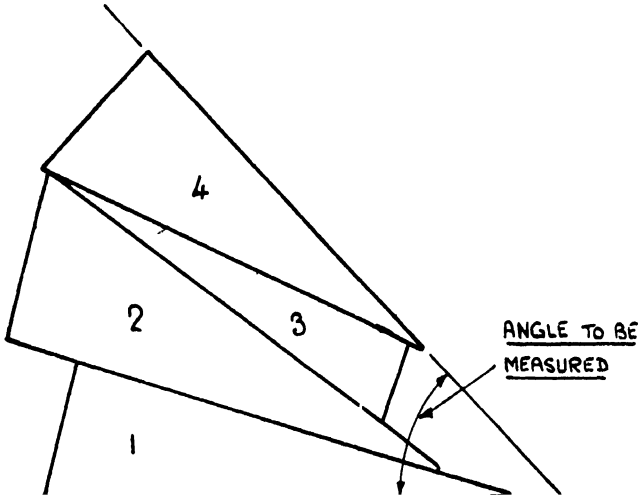


Fig. 127.—ANGLE-BLOCK GAUGES

When ascertaining the height of any point by means of ordinary block gauges, the thicknesses of all the blocks are added together. In the case of angle blocks, the angle of any particular block can be subtracted from the total of the other angles by arranging it with the thin end opposite to the thin ends of the other gauges. To check an angle as shown in Fig. 127, the angular measurement is given by the total of the angles of numbers 1, 2, and 4 gauges, less the angle of number 3 gauge.

The degree of accuracy is to within 2 secs. of the angle between the face to be measured and the datum.

To give accurate measurement, the end faces of the gauges must be set parallel, the angle blocks being wrung together, as is done with ordinary block gauges.

Chapter XI

GEAR MEASUREMENT

GEARING is a specialised subject, and it is impossible to attempt to describe fully all the various kinds and designs of gears within the scope of this volume. However, it is proposed to set out most of the details as applicable to inspection practice, and to describe the fundamental terms and methods of gear measurement.

Those desiring to acquire a wider knowledge of the subject should refer to the current British Standard Specifications and other authoritative works.

Spur Gears

Spur gears are those in which the teeth are parallel to the axis, and are used to connect shafts whose axes are parallel. Of two gears which mesh together, the one with the smallest number of teeth is called the pinion, and the other the wheel. An exception to this is in the case of worm gearing, where the gear with the smallest number of teeth is called the worm, and the other the worm wheel. In the case of a gear whose teeth lie in a straight line, instead of a circle, this is called a rack, and is really part of a wheel of infinite size.

DEFINITION OF INVOLUTE-GEAR TERMS (Fig. 128)

Pitch-circle Diameter, or Pitch Diameter

The word diameter, as applied to a gear, is understood to mean the pitch circle, or pitch diameter. This represents the diameter of an imaginary circle which is intermediate between the top and bottom of the teeth.

Pitch

The pitch of a gear can be expressed in two ways, circular and diametral pitch.

CIRCULAR PITCH.—This is the distance from a point on one tooth to the corresponding point on the next consecutive tooth.

DIAMETRAL PITCH.—This is the number of teeth in the gear for each inch in the pitch diameter, and can be expressed :

$$\frac{\text{No. of Teeth in Gear}}{\text{Pitch Circle Diameter}}.$$

Addendum

The addendum is the distance from the pitch circle to the top of the tooth. Twice this distance represents the working depth of the tooth.

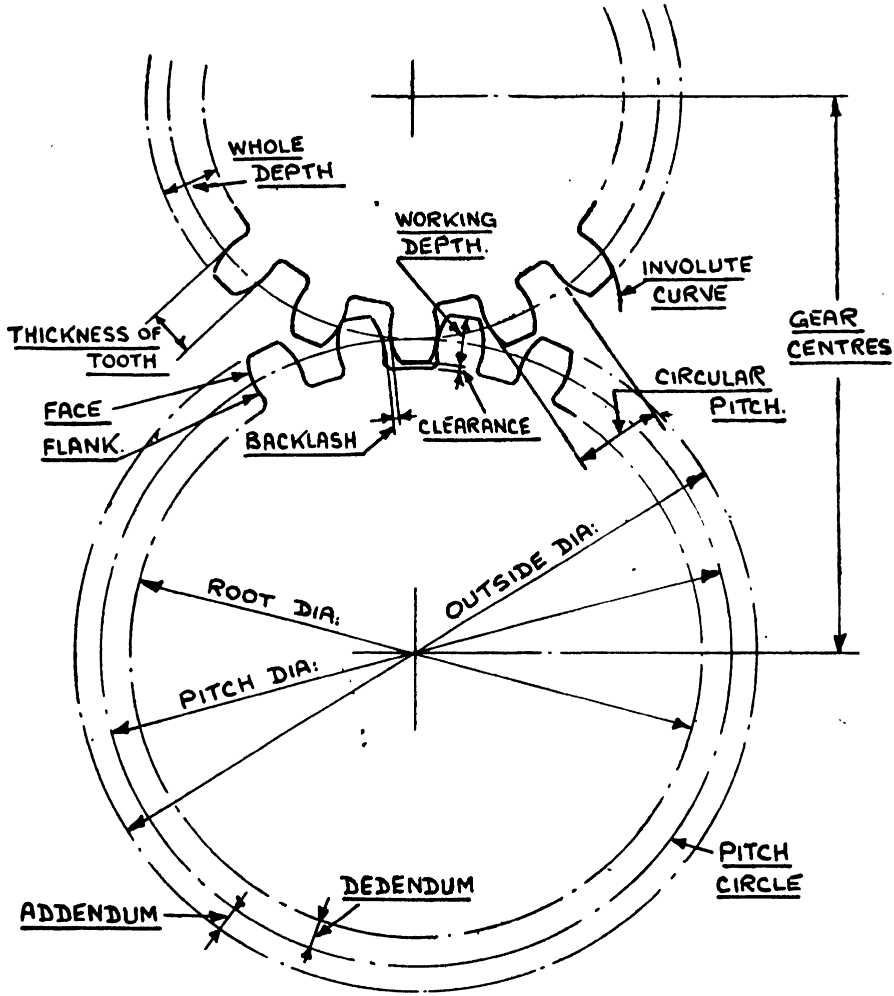


Fig. 128.—INVOLUTE GEAR TERMS

Dedendum

This is the distance from the pitch circle to the bottom of the tooth, and the difference between the addendum and dedendum represents the *clearance*.

Root Diameter is the diameter taken at the bottom of the tooth spaces.

Outside Diameter

This is the diameter taken over the tops of the teeth.

Tooth Thickness

The length of arc of the pitch circle between the faces of a tooth.

Chordal Thickness of a Tooth (Fig. 129)

The length of the chord subtended by the arc of the pitch circle contained in the tooth thickness.

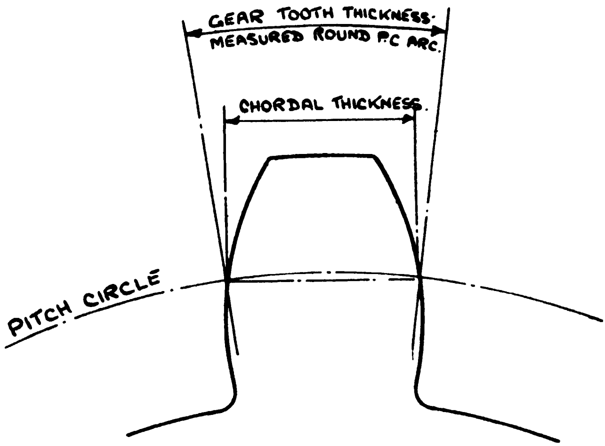


Fig. 129.—CHORDAL THICKNESS OF A TOOTH

Base Circle

The circle from which the involute is generated.

Line of Action (Fig. 130)

The tangent common to both base circles of a pair of meshing gears, and passing through their pitch point.

Path of Contact

The part of the line of action on which tooth contact is affected.

Angle of Pressure (Fig. 130)

The angle which the line of mutual action makes with the common tangent to both pitch circles at their point of contact, or pitch point. Originally 14½° was adopted as the standard angle of pressure, to avoid excessive thrust taking place between mating gears and consequent pressure on the bearings. This has now been superseded by an angle of 20° as recommended by the British Standards Institution.

Arc of Approach

The arc of the pitch circle travelled by a tooth from the time of contact with its meshing tooth until it contacts at the line of centres.

Arc of Recession

The arc of the pitch circle travelled by a tooth after it contacts its meshing tooth at the line of centres until such contact is broken.

Fillet

The radius at the bottom of the tooth.

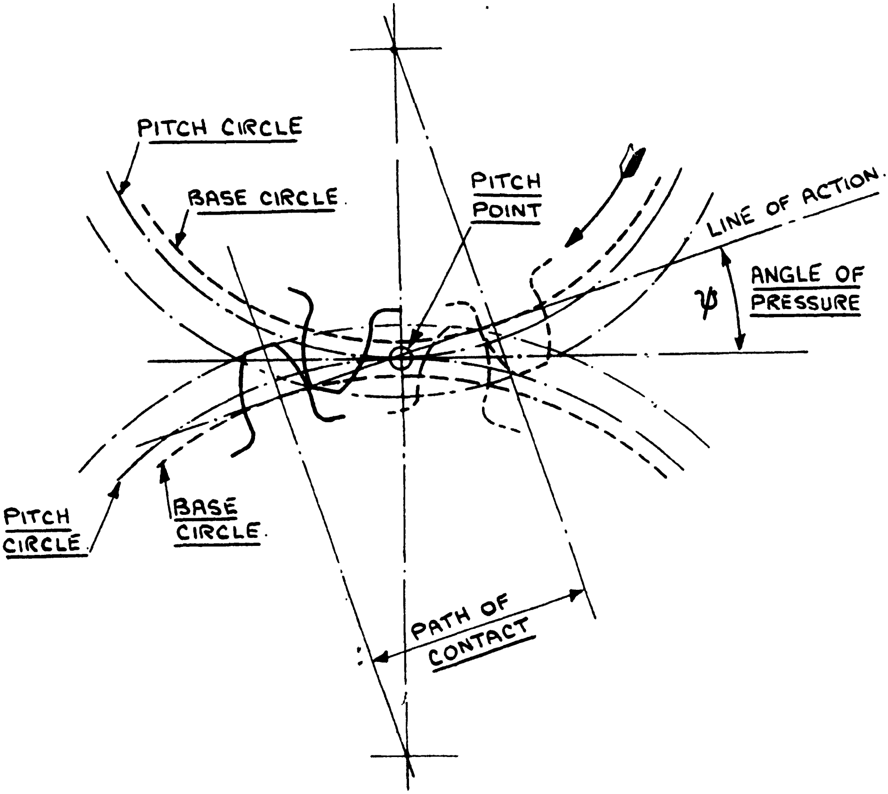


Fig. 130.—LINE OF ACTION, ANGLE OF PRESSURE AND PATH OF CONTACT

Backlash

The smallest clearance between the surfaces opposite to the driving surfaces of a meshing pair of teeth.

Proportions for Machine-cut Spur Gears

$$\text{Circular Pitch} = \frac{\text{Pitch Diameter} \times \pi}{\text{No. of Teeth}}$$

$$\text{Diametral Pitch} = \frac{\text{No. of Teeth}}{\text{Pitch Diameter}}$$

Pitch Diameter $= \dfrac{\text{No. of Teeth}}{\text{Diametral Pitch}}$ or $\dfrac{\text{No. of Teeth} \times \text{Circular Pitch}}{3{\cdot}1416}$

Outside Diameter $= \dfrac{\text{No. of Teeth} + 2}{\text{Diametral Pitch}}$

or Pitch Diameter $+ ({\cdot}3183 \times \text{Circular Pitch} \times 2)$

Thickness of Tooth at Pitch Line $= \dfrac{1{\cdot}5708}{\text{Diametral Pitch}}$ or $\dfrac{\text{Circular Pitch}}{2}$

Space Width $= {\cdot}5 \times$ Circular Pitch

Addendum $= \dfrac{1}{\text{Diametral Pitch}}$ or ${\cdot}3183 \times$ Circular Pitch

Dedendum $= \dfrac{1{\cdot}157}{\text{Diametral Pitch}}$ or ${\cdot}3683 \times$ Circular Pitch

Working Depth of Tooth $= \dfrac{2}{\text{Diametral Pitch}}$ or ${\cdot}6366 \times$ Circular Pitch

Whole Depth of Tooth $= \dfrac{2{\cdot}157}{\text{Diametral Pitch}}$ or ${\cdot}6866 \times$ Circular Pitch

No. of Teeth $= \dfrac{\text{Circumference of Pitch Circle}}{\text{Circular Pitch}}$

or Diametral Pitch $\times$ Pitch Circle Diameter

Corresponding Diametral Pitch $= \dfrac{\pi}{\text{Circular Pitch}}$

Corresponding Circular Pitch $= \dfrac{\pi}{\text{Diametral Pitch}}$

Centres of Gear Wheels $= \dfrac{\text{Pitch Diameter of Wheel} + \text{Pitch Diameter of Pinion}}{2}$

or $\dfrac{\text{No. of Teeth in Wheel} + \text{No. of Teeth in Pinion}}{2 \times \text{Diametral Pitch}}$

Gears having cast teeth are seldom used except for the roughest classes of work. Circular pitches are generally employed, and the proportions, differing from machine-cut gears, can be taken as follows :

Outside Diameter = Pitch Diameter + (·3 Circular Pitch × 2)
Thickness of Tooth at Pitch Line = Circular Pitch × ·48
Addendum = Circular Pitch × ·3
Dedendum = Circular Pitch × ·45
Working Depth of Tooth = Circular Pitch × ·6
Whole Depth of Tooth = Circular Pitch × ·75
Space Width = Circular Pitch × ·52

For British Standards Institute Standard, the following applies :

Addendum = Circular Pitch × ·3183

Dedendum = Circular Pitch × ·3979 — Circular Pitch × ·4583

Tooth Thickness = Circular Pitch × ·5

Space Width = Circular Pitch × ·5

The Diameter of Base Circle can be found from :

Diameter of Base Circle = Pitch Diameter × Cosine of Angle of Pressure,

which for $14\frac{1}{2}°$ Angle of Pressure is :

Pitch Diameter × ·9682

and for 20° Angle of Pressure is :

Pitch Diameter × ·9397

Before proceeding farther, consideration must be given to the profile of gear teeth. The involute form of tooth has found the more general favour in modern toothed gears, although both involute and cycloidal curves are regarded as the standard forms.

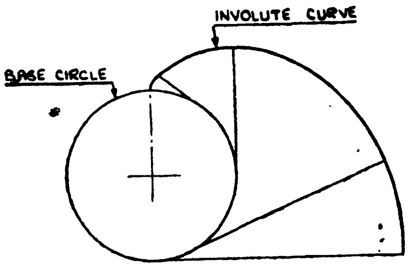


Fig. 131.—THE INVOLUTE CURVE

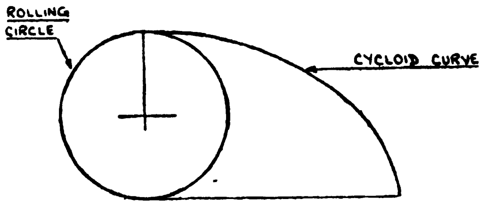


Fig. 132.—THE CYCLOID CURVE

Involute (Fig. 131)

An involute can be defined as the curve described by the end of a flexible, inextensible cord as it unwinds from a cylinder. The circle forming the cylinder is called the base circle of the involute. The involute form of tooth has theoretically one curve, which forms both face and flank of the tooth side.

Cycloid (Fig. 132)

A cycloid is the curve described by a point on the circumference of a circle rolling along a straight line. The cycloid, or double-curved gear teeth, generally have convex faces and concave flanks.

All data given in this chapter is based on the involute curve, as the limits of this book will not allow further considerations.

Rack Teeth (Fig. 133)

If the diameter of the pitch circle of a spur wheel is increased to infinity, the circumference of the pitch circle will ultimately become a straight line. This line is called the pitch line of the rack, and therefore

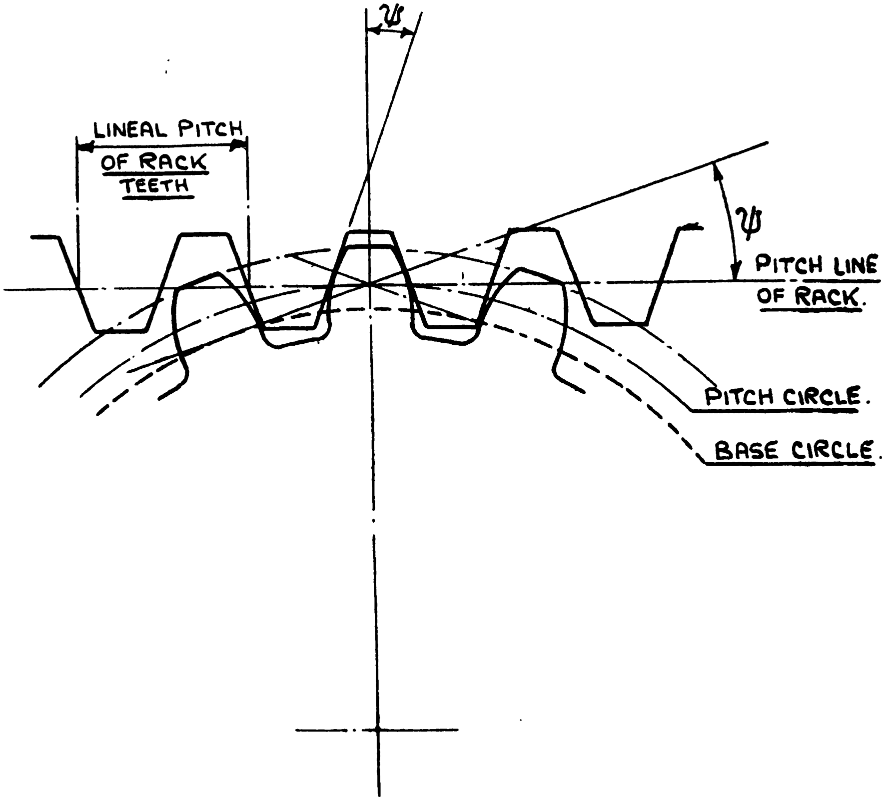


Fig. 133.—Involute pinion and rack

the pitch of rack teeth is best expressed as lineal pitch. Involute gears, providing the pitch, the angle of pressure and tooth proportions are the same, are interchangeable, and in the case of rack teeth the working profile is formed of straight lines, inclined at the angle of pressure. The B.S.I. basic rack teeth are shown in Figs. 134A and B.

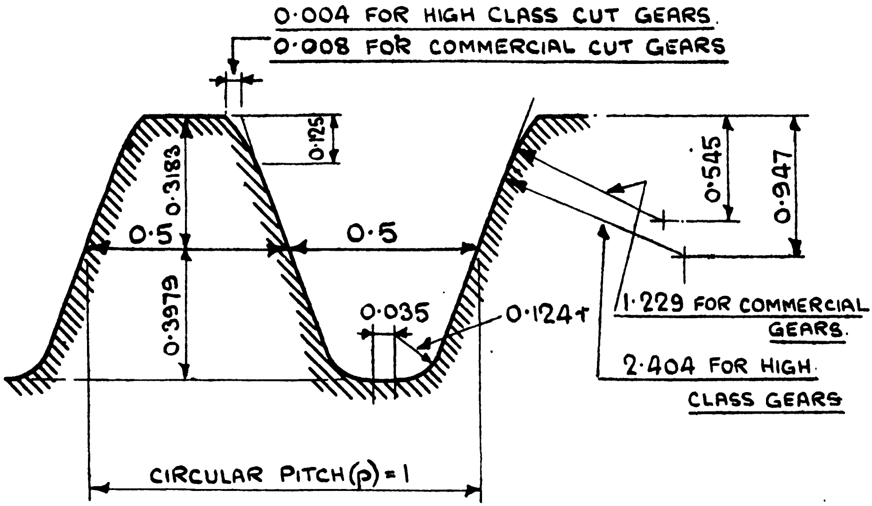


Fig. 134A.—B.S.I. BASIC RACK TEETH

Metric Pitches

Where the metric system is employed, the pitch of gear teeth is expressed in modules. A module is the pitch diameter in millimetres, divided by the number of teeth in the gear. From this it is seen that the pitch diameter = Module × Number of Teeth in Gear.

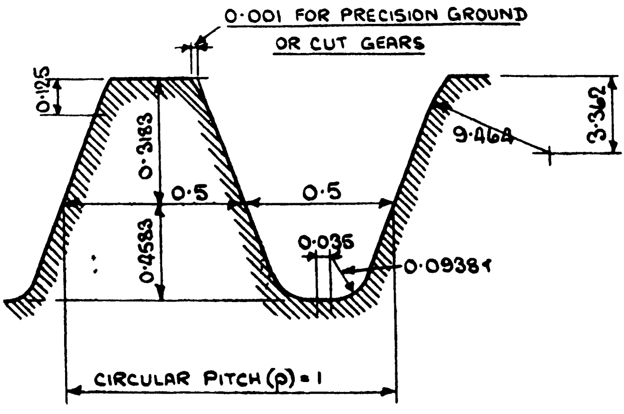


Fig. 134B.—B.S.I. BASIC RACK TEETH

When dealing with metric pitches, the following formulæ will be found useful:

$$\text{Module} = \frac{\text{Pitch Diameter}}{\text{No. of Teeth}}$$

Pitch Diameter = No. of Teeth × Module

Outside Diameter = (No. of Teeth + 2) × Module

Addendum = Module

Dedendum = Module + (Module × ·157)
Thickness of Tooth = Module × 1·5708
Working Depth = 2 × Module
Whole Depth = 2 × Module + (Module × ·157)
Clearance = Module × ·157

$$\text{No. of Teeth} = \frac{\text{Pitch Diameter}}{\text{Module}}$$

Bevel Gears

Bevel gears can be defined as gears used to connect shafts whose axes would meet if they were extended.

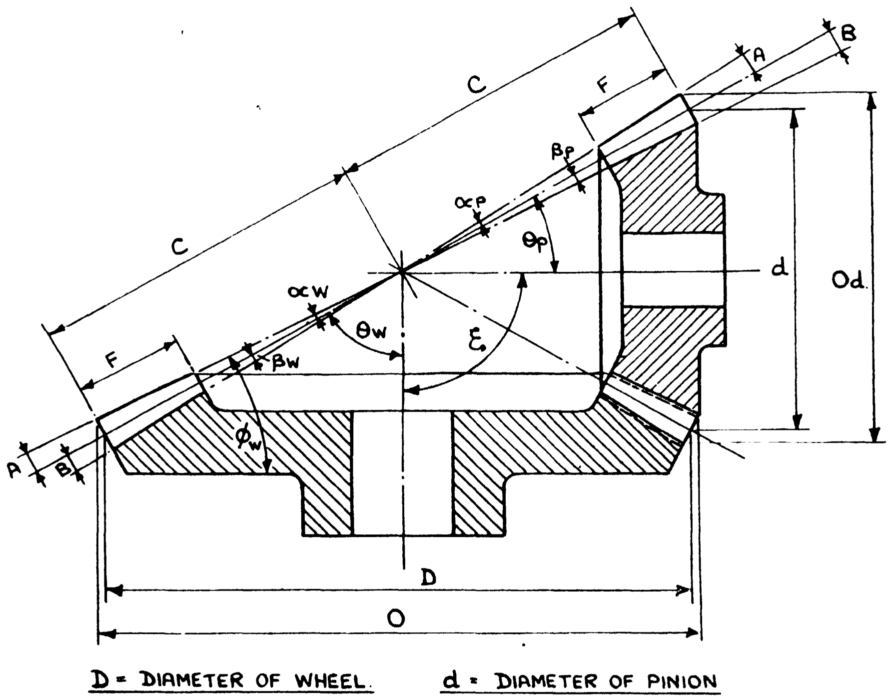


Fig. 135.– B.S.I. TERMINOLOGY FOR BEVEL WHEELS

The abbreviations are :

D. Pitch diameter of wheel.
C. Cone (or Apex) distance.
A. Addendum.
B. Dedendum.
O. Outside diameter.
ϕ. Face angle.
F. Face width.
θ. Pitch angle.
α. Addendum angle.
β. Dedendum angle.
ξ. Shaft angle.

The teeth of these gears are formed on the frustra of imaginary cones, known as "pitch cones." These cones have their common apex at the point of intersection of the axes of the shafts, and it is on this point that all parts of the teeth converge.

When these gears are used for connecting shafts whose axes are at right angles to each other, and which are both the same diameter, having, therefore, a pitch angle of 45°, they are known as mitre gears.

The B.S.I. has standardised the terminology of bevel wheels and pinions, and the illustration shown in Fig. 135 conforms to this method.

Formulæ for Bevel Gears with Shaft Angle of 90°

$$\text{Pitch Diameter} = \frac{\text{No. of Teeth in Pinion}}{\text{Diametral Pitch}} \text{ for Pinion}$$

$$\frac{\text{No. of Teeth in Wheel}}{\text{Diametral Pitch}} \text{ for Wheel}$$

$$\text{Outside Diameter} = \text{Pitch Diameter} + \left(\text{Cos Pitch Angle} \times \frac{2}{\text{DP}}\right)$$

or Pitch Diameter + (2 Addendum × Cos Pitch Angle)

$$\text{Tan Pitch Angle for Pinion} = \frac{\text{No. of Teeth in Pinion}}{\text{No. of Teeth in Wheel}}$$

$$\text{Tan Pitch Angle for Wheel} = \frac{\text{No. of Teeth in Wheel}}{\text{No. of Teeth in Pinion}}$$

$$\text{Tan Addendum Angle } (\alpha) = \frac{2 \times \text{Sine Pitch Angle}}{\text{No. of Teeth in Pinion}}$$

$$\text{or } \frac{2 \times \text{Sine Pitch Angle}}{\text{No. of Teeth in Wheel}}$$

$$\text{Tan Dedendum Angle } (\beta) = \frac{1{\cdot}157}{\text{Diametral Pitch} \times C}$$

$$\text{or } \frac{2{\cdot}3141 \text{ Sine Pitch Angle}}{\text{No. of Teeth in Gear}}$$

Face Angle (ϕ) = Pitch Angle + Addendum Angle

$$\text{Cone Distance} = \frac{\text{Pitch Diameter}}{2 \times \text{Sine Pitch Angle}}$$

Cutting, or Base Angle = Pitch Angle − Dedendum Angle

Where the shaft angle is less than 90°, the pitch angle of wheel or pinion can be found from :

$$\text{Tan of Pitch Angle of Pinion} = \frac{\text{Sine Shaft Angle}}{\frac{n}{N} + \text{Cos Shaft Angle}}$$

$$\text{Tan of Pitch Angle of Wheel} = \frac{\text{Sine Shaft Angle}}{\frac{N}{n} + \text{Cos Shaft Angle}}$$

where N = No. of Teeth in Pinion and n = No. of Teeth in Wheel.

When the shaft angle is greater than 90°, the following can be used to find the pitch angle of the wheel or pinion :

$$\text{Tan Pitch Angle of Pinion} = \frac{\text{Sine }(180^\circ - \text{Shaft Angle})}{\frac{n}{N} - \text{Cos }(180^\circ - \text{Shaft Angle})}$$

$$\text{Tan Pitch Angle of Wheel} = \frac{\text{Sine }(180^\circ - \text{Shaft Angle})}{\frac{N}{n} - \text{Cos }(180^\circ - \text{Shaft Angle})}$$

The addendum and dedendum angles can be obtained from :

$$\text{Tan of Addendum Angle} = \frac{2 \times \text{Sine Pitch Angle}}{\text{No. of Teeth}}$$

$$\text{Tan of Dedendum Angle} = \frac{\text{Dedendum}}{\text{Cone Distance}}$$

Note.—For Diametral Pitch Gears the Dedendum $= \dfrac{1{\cdot}157}{\text{Diametral Pitch}}$

and for Circular Pitch Gears the Dedendum = ·3683 × Circular Pitch.

Gear-tooth Vernier Calipers (Fig. 136)

This type of caliper measures the " chordal " thickness T of the tooth and at the same time the Addendum A (see Fig. 137). It should be observed that modification must be made to the reading when measuring the addendum, owing to the height of the arc H. When a gear tooth is being measured, the height of the arc H must be added to the addendum A, and when a cutter is being measured, the height of the arc must be subtracted from $A + f$, where f = working clearance.

The gear-tooth vernier is a combination of two sliding scales, operating at right angles, and each reading independently. The set of jaws, arranged as in the vernier caliper, is set to the thickness of the tooth at the pitch line. The vertical scale, which in effect is a depth gauge, is set to the addendum. Both vernier readings are taken in the same manner as with the ordinary vernier caliper.

The tables given show the chordal thickness T, for gears and cutters, the height of the arc H, the corrected $A + f$ for the cutter, and the corrected $\dot{A}$ for the gear for both involute and cycloidal form teeth.

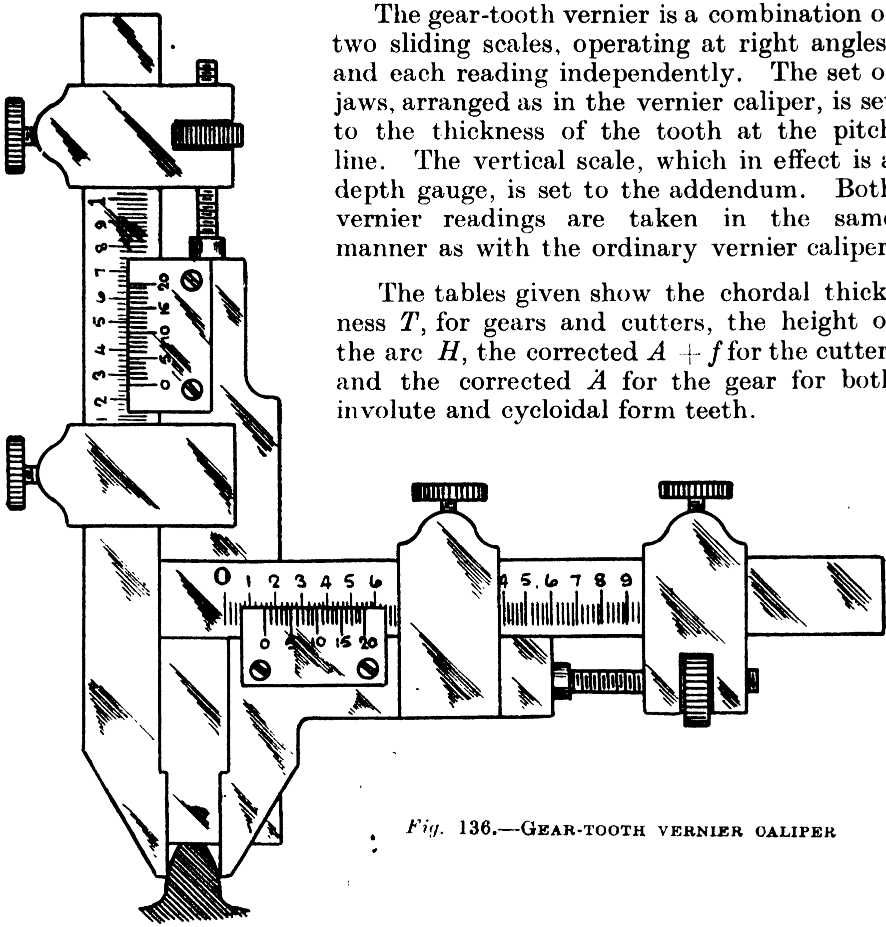


Fig. 136.—GEAR-TOOTH VERNIER CALIPER

The tables are calculated on a basis of 1 diametral pitch, and when used for other pitches the figures given must be divided by that particular pitch. As an example, given a gear of 26 teeth, 4 diametral pitch of involute form :

Then reading $$T = \frac{1{\cdot}5698}{4} = {\cdot}39245 \text{ in.}$$

and for vertical reading $$(A + H) = \frac{1{\cdot}0237}{4} = {\cdot}25592 \text{ in.}$$

When checking the accuracy of the cutter, the chordal thickness T

is the same as for the gear tooth, but the vertical reading is found by dividing the number in the corrected $A + f$ column by the diametral pitch :

$$\text{As } \frac{1\cdot1334}{4} = \cdot28335 \text{ in.}$$

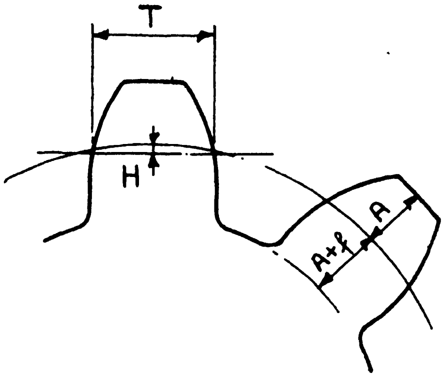


Fig. 137.—CHORDAL THICKNESS AND ADDENDUM

The chordal thickness T can be found from the formula

$$T = \frac{\text{Pitch Diameter} \times \text{Sine } 90^\circ}{\text{No. of Teeth}}$$

TABLE FOR INVOLUTE TEETH

Cutter	*T*	*H*	*Corrected A + f for Cutter*	*Corrected A for Gear*
No. 1 – 135T–1 DP . .	1·5707	·0047	1·1524	1·0047
,, 1½– 80T–1 DP . .	1·5707	·0077	1·1494	1·0077
,, 2 – 55T–1 DP . .	1·5706	·0112	1·1459	1·0112
,, 2½– 42T–1 DP . .	1·5704	·0147	1·1424	1·0147
,, 3 – 35T–1 DP . .	1·5702	·0176	1·1395	1·0176
,, 3½– 30T–1 DP . .	1·5701	·0205	1·1366	1·0205
,, 4 – 26T–1 DP . .	1·5698	·0237	1·1334	1·0237
,, 4½– 23T–1 DP . .	1·5696	·0268	1·1303	1·0268
,, 5 – 21T–1 DP . .	1·5694	·0294	1·1277	1·0294
,, 5½– 19T–1 DP . .	1·5690	·0324	1·1247	1·0324
,, 6 – 17T–1 DP . .	1·5686	·0362	1·1209	1·0362
,, 6½– 15T–1 DP . .	1·5679	·0411	1·1160	1·0411
,, 7 – 14T–1 DP . .	1·5675	·0440	1·1131	1·0440
,, 7½– 13T–1 DP . .	1·5670	·0474	1·1097	1·0474
,, 8 – 12T–1 DP . .	1·5663	·0514	1·1057	1·0514
– 11T–1 DP . .	1·5654	·0559	1·1011	1·0559
– 10T–1 DP . .	1·5643	·0616	1·0955	1·0616
– 9T–1 DP . .	1·5625	·0684	1·0887	1·0684
– 8T–1 DP . .	1·5607	·0769	1·0802	1·0769

TABLE FOR CYCLOIDAL TEETH

Cutter	*T*	*H*	*Corrected A + f for Cutter*	*Corrected A for Gear*
A– 12T–1 DP . . .	1·5663	·0514	1·1057	1·0514
B– 13T–1 DP . . .	1·5670	·0474	1·1097	1·0474
C– 14T–1 DP . . .	1·5675	·0440	1·1131	1·0440
D– 15T–1 DP . . .	1·5679	·0411	1·1160	1·0411
E– 16T–1 DP . . .	1·5683	·0385	1·1186	1·0385
F– 17T–1 DP . . .	1·5686	·0362	1·1209	1·0362
G– 18T–1 DP . . .	1·5688	·0342	1·1229	1·0342
H– 19T–1 DP . . .	1·5690	·0324	1·1247	1·0324
I– 20T–1 DP . . .	1·5692	·0308	1·1263	1·0308
J– 21T–1 DP . . .	1·5694	·0294	1·1277	1·0294
K– 23T–1 DP . . .	1·5696	·0268	1·1303	1·0268
L– 25T–1 DP . . .	1·5698	·0247	1·1324	1·0247
M– 27T–1 DP . . .	1·5699	·0228	1·1343	1·0228
N– 30T–1 DP . . .	1·5701	·0208	1·1363	1·0208
O– 34T–1 DP . . .	1·5703	·0181	1·1390	1·0181
P– 38T–1 DP . . .	1·5703	·0162	1·1409	1·0162
Q– 43T–1 DP . . .	1·5705	·0143	1·1428	1·0143
R– 50T–1 DP . . .	1·5705	·0123	1·1448	1·0123
S– 60T–1 DP . . .	1·5706	·0102	1·1469	1·0102
T– 75T–1 DP . . .	1·5707	·0083	1·1488	1·0083
U–100T–1 DP . . .	1·5707	·0060	1·1511	1·0060
V–150T–1 DP . . .	1·5707	·0045	1·1526	1·0045
W–250T–1 DP . . .	1·5708	·0025	1·1546	1·0025

The height of the arc H can be found from the formula :

$$H = \text{Pitch Radius of Gear} \times (1 - \cos \alpha)$$

where $\alpha = 90°$ divided by number of teeth.

Sykes Gear-tooth Comparator (Fig. 138)

The Sykes gear-tooth comparator consists of a beam which carries one fixed and one movable jaw, in addition to a special dial-test indicator. The plunger of the dial indicator projects between the comparator jaws. The comparator is set to a master-gauge block, which is of involute rack tooth form, of a particular pitch and pressure angle. The jaw faces are made correspondingly. When the comparator is set to a master-gauge block, the setting is correct for all teeth having the same thickness, pressure angle, and addendum as that particular block.

When checking a tooth, any variation from the setting will show plus or minus on the dial indicator, owing to the tooth entering between the jaws at a smaller or greater distance than allowed on the gauge. One division on the dial represents ·0005 in. for a pressure angle of $14\frac{1}{2}°$.

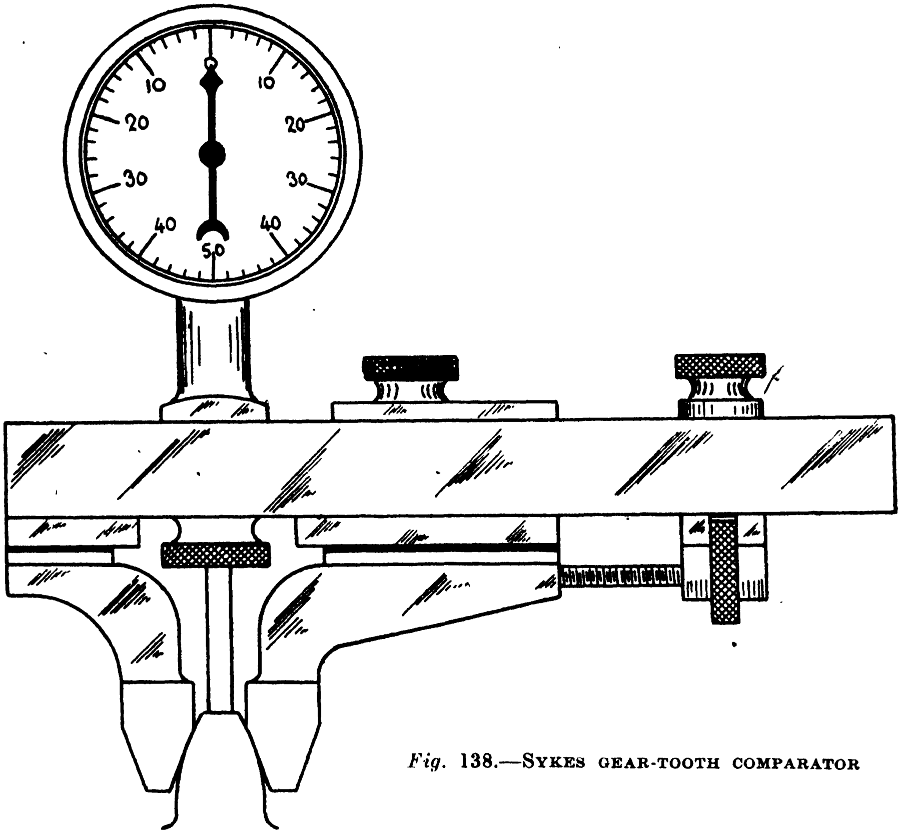


Fig. 138.—SYKES GEAR-TOOTH COMPARATOR

The jaws of the comparator and the gauge block are hardened, ground, and lapped.

The standard gauge blocks have a pressure angle of $14\frac{1}{2}°$, but any particular angle is obtainable with special blocks. Seven blocks will cover the range of all pitches, six a range between 12 D.P. and $1\frac{1}{2}$ D.P., and four the range between 12 D.P. and 3 D.P. The range of the comparator is 12 D.P. to 1 D.P., or $\frac{1}{4}$ in. to 3 in. C.P.

The principle of the comparator is the same as the Sykes gear-tooth caliper, and is illustrated in Fig. 139.

It is obvious that when setting the comparator to the gauge block, the dial indicator must register zero.

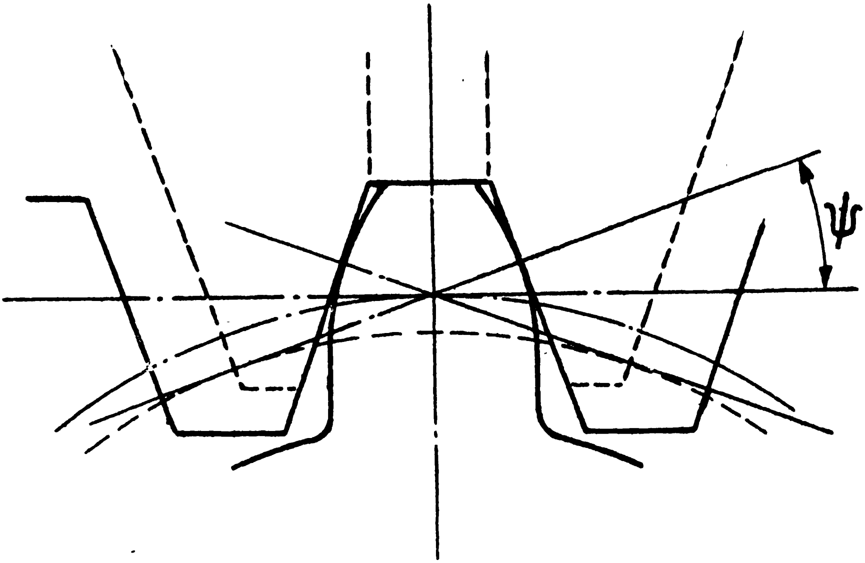


Fig. 139.—PRINCIPLE OF SYKES GEAR-TOOTH CALIPER

The Sykes Gear-tooth Caliper (Fig. 140)

It will be seen from the illustration that the Sykes gear-tooth caliper is very similar to the ordinary vernier caliper gauge, but that the jaws represent the rack form. The principle of the caliper is shown in Fig. 139, where the dotted lines represent the jaws of the caliper. The lines of pressure (or action) are those on which the tooth contact will always occur.

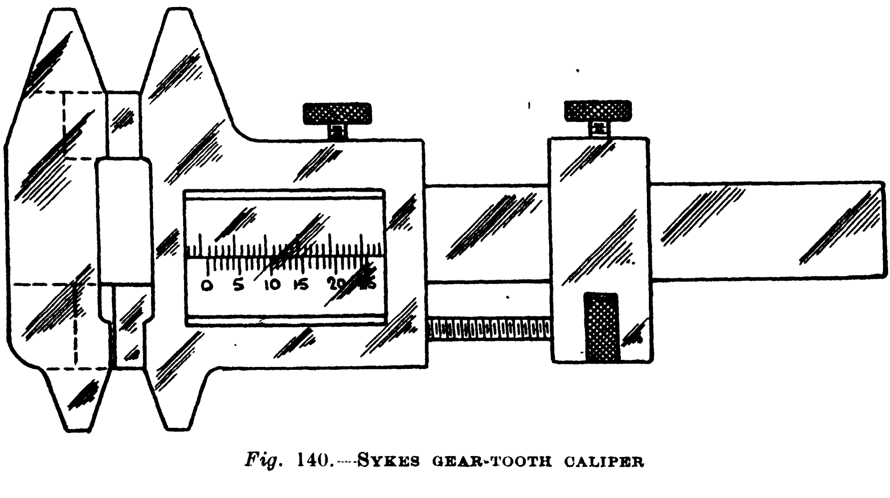


Fig. 140.—SYKES GEAR-TOOTH CALIPER

irrespective of size, or the number of teeth in the gear. These lines are always the same for any given pressure angle, and as they pass through the pitch point and are normal to the rack-tooth profile, they conform to the first law of gear-tooth contact, which states that "the common normal to the tooth curves must pass through the pitch."

From this it is seen that contact will always take place on the lines of action, and that the actual point of contact is dependent only upon the thickness of the tooth. Although for each number of teeth in the gears of any particular pitch the profile of the teeth will be different, the point of contact with the centre line of the tooth and corresponding tooth space is always the same.

Measurement of Gear-tooth Thickness with Micrometer (Fig. 141)

The method of measuring the gear-tooth thickness as shown in the illustration is suitable only for gears having involute teeth. It is based on the fact that, when measured along a tangent to the base circle, the distance between any two involute profiles oppositely facing one another is the same whatever the position of the tangent. If the micrometer is held so that its anvil and spindle touch the two teeth as shown, the micrometer reading will be the same wherever it touches the teeth along the profile.

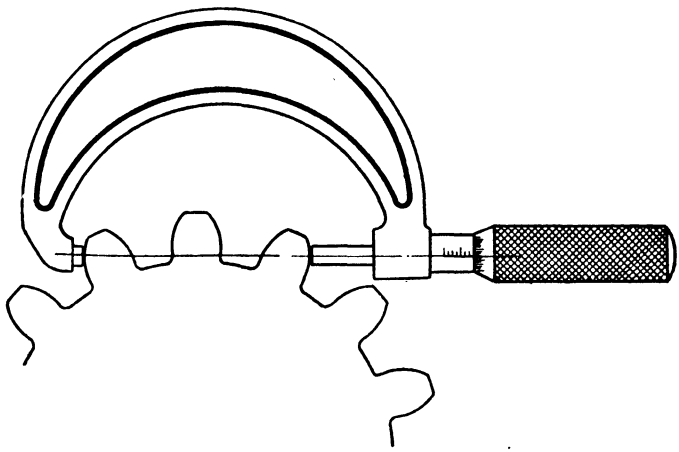


Fig. 141.—MICROMETER MEASUREMENT OF GEAR-TOOTH THICKNESS

Formula for Micrometer Measurement of Tooth Thickness

Before using the formula it is necessary to calculate the "involute function." This is simply a numerical value dependent on a particular angle, and is obtained by expressing the angle in radians and subtracting it from the tangent of the angle derived from mathematical tables. This function is sometimes introduced in the form, inv. sec. $\frac{-1d}{d_0}$, which means, find the angle whose secant is $\frac{d}{d_0}$, where d = diameter of circle on

which the tooth thickness is measured and d_o = diameter of base circle, and then find the involute function by subtracting its value in radians from the value of its tangent. To express an angle in radians, multiply the number of degrees by $\pi/180°$. The involute function of an angle of 10° is equal to :

$$\tan 10° - \frac{10 \times \pi}{180°} = \cdot 17633 - \cdot 17453 = \cdot 00180$$

and this would be written, inv. 10° = ·00180.

FORMULA

Let r_o = radius of base circle = $pt \cos \Psi/2\pi$.

p = pitch of teeth on circle of radius r.

s = thickness of teeth on circle of radius r.

Ψ = pressure angle of teeth on circle of radius r.

n = number of teeth between micrometer spindle and anvil.

t = number of teeth in gear.

m = micrometer measurement.

Then $\cos \Psi = r_o/r = pt \cos \Psi/2\pi r$

and $$m = r_o \left[\frac{s}{r} + \frac{2\pi(n-1)}{t} + 2 \text{ inv. } \Psi\right].$$

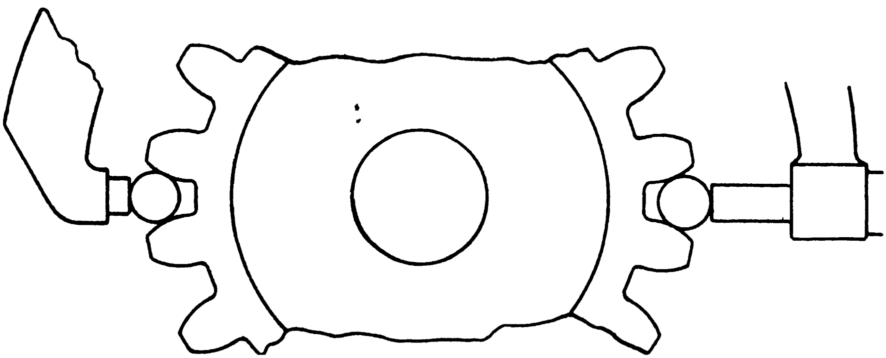


Fig. 142.—MICROMETER MEASUREMENT OVER ROLLERS

Micrometer Measurement over Rollers (Fig. 142)

Gear-tooth thickness can be measured by micrometer, over rollers placed in the two tooth spaces as shown. The rollers may be of any diameter within a limited range, but for simplicity of measurement, suitably chosen rollers should be employed.

FORMULA

Let p = pitch of cutter.
Ψ = pressure angle of cutter.
s = tooth thickness required on generating pitch circle.
t = number of teeth in gear.
d = roller diameter.
Then $d = (p\text{-}s) \cos \Psi$

and micrometer measurement over rollers

$$= \frac{tp}{\pi} + d \text{ for rollers in opposite spaces,}$$

when the number of teeth is odd, it is obvious that the spaces will not be opposite. In such cases, the spaces as nearly opposite as possible are taken, and the following formula employed :

$$\frac{tp}{\pi}\left(1 - 2\sin^2\frac{45^\circ}{t}\right) + d$$

Checking by running Gears in Mesh

If two gears are mounted in bearings and run together at light load, the teeth of one gear being slightly smeared with prussian blue, the latter will spread on to the teeth of the mating gear, and show whether or not a uniform tooth contact is being made. From the results of this test, any necessary adjustments can be made and the gears run again together, this time at full speed under varying loads. If they run reasonably quietly, it can be concluded that any errors they possess will not affect the gears during normal working conditions.

An error in the tooth form can be detected by the high-pitched note heard when the gears are under test. Pitch error in one of the gears is detected by a beat in the noise for every revolution of that particular gear. Pitch error may be present in both gears, and the noise produced during test may show a beat each time the two worst places mesh together. In gears having numbers of teeth which do not possess a common factor, the previously mentioned fault is evident each time the pinion makes the number of revolutions equal to the number of teeth in the wheel.

The " David Brown " Involute Testing Instrument

The instrument shown in Fig. 143 by Messrs. David Brown & Sons (Hudd.) Ltd. has been designed to provide simple and reliable means of checking the accuracy of an involute-gear tooth. It can deal with spur or helical gears and worm wheels, and be adjusted to accommodate gears up to 12-in. base-circle diameter.

Direct reading is obtained on a dial indicator, which shows deviations of $\frac{1}{10000}$ in. of the tooth form from correct involute, and consistent accuracy is maintained.

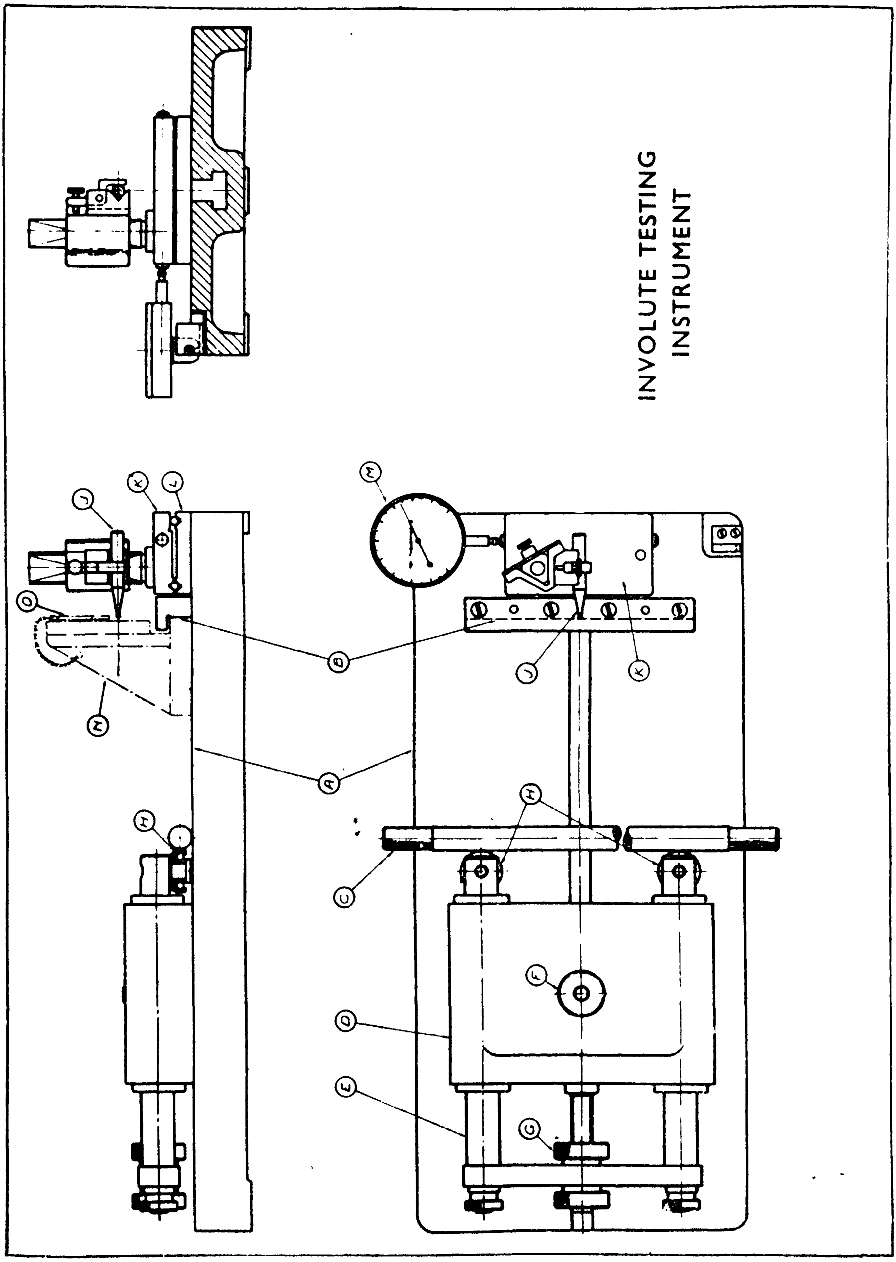


Fig. 143.—ARRANGEMENT OF THE INSTRUMENT
(*By courtesy of David Brown & Sons (Hudd.) Ltd.*)

Fig. 144 shows the principle of operation. The gear is arranged with its centre at A 1, and its base disc contacting the straightedge at B 1. The stylus is brought into contact with the involute at C. By rolling the base disc along until the centre is at A 2, and the contacting point at B 2, the stylus, providing the involute is true, will still occupy the same position C when in contact with the tooth profile and the indicator will remain at zero. Deviation from the true involute form will cause a corresponding change in the indicator reading, thus directly measuring the amount of error.

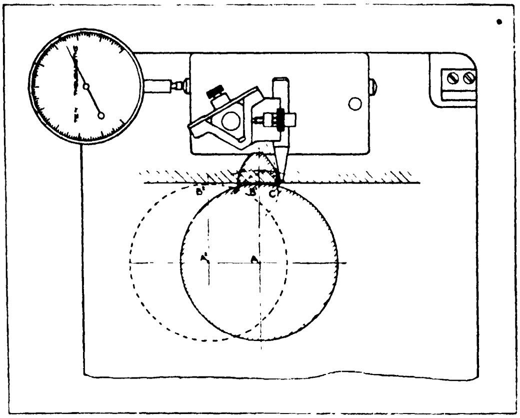


Fig. 144.—PRINCIPLE OF OPERATION
(*By courtesy of David Brown & Sons (Hudd.) Ltd.*)

Construction of the "DBS" Instrument

The base A carries the whole of the instrument, and is of heavy section, close-grained, and well-seasoned cast iron accurately machined.

The gear being checked is mounted on an arbor, and concentric with a " base disc " whose diameter is equal to the base-circle diameter of the gear. The ground periphery of the base disc contacts a hardened and ground reference face B over which it rolls, while the under face rests on, and slides over, the surface of the base plate. The instrument is operated by means of the hardened and ground, circular-section steel rod C, set parallel to the face of B, the base disc being held between B and C. By moving C in either direction, friction is set up, causing the base disc to roll along the surface of B without slip. Sufficient compression between the surfaces is applied through the cast-iron slide D, mounted on the base plate, and carrying two case-hardened steel, accurately ground and polished compression plungers E, which slide in hardened and ground bushes. The plunger rods move laterally and rotate the base disc by means of the ball bearings H provided at their forward ends. The slide D can be locked in any desired position by a turn of the nut F, which tightens the " Tee "-section bolt running in the slot in the base plate. A steel tie-bar connects the plungers together, and final adjustment and correct compression are obtained by means of the knurled nut G.

When the gear tooth is rolled past the point of the hardened and ground stylus J, any deviation from the true involute curve is indicated on the dial indicator M, which is graduated in divisions of ·0001 in. The

stylus is mounted on a carriage K in a horizontal " Vee " bracket, and held in position by a suitable clamp.

Vertical motion is obtained by the " Vee " bracket sliding on a triangular section pillar, which provides an effective means of rigid locking. Frictionless lateral motion of the carriage is ensured by means of

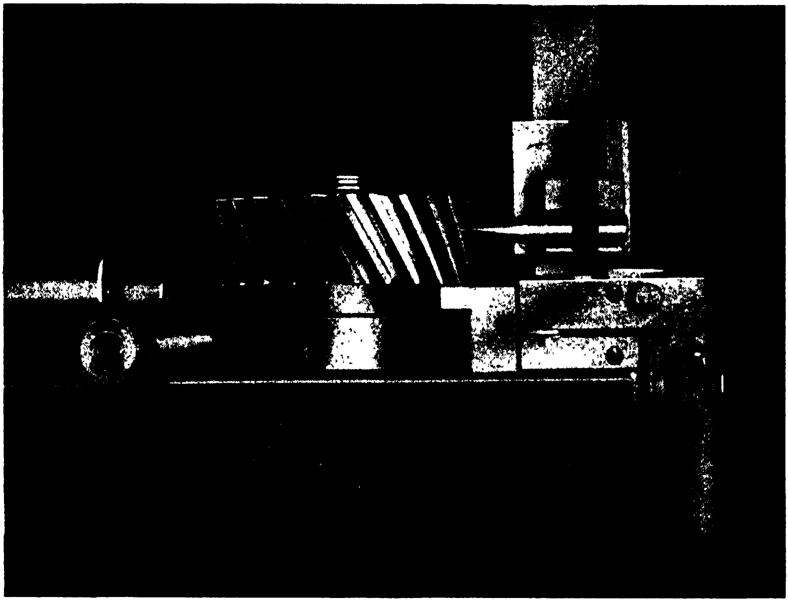


Fig. 145.—TESTING OF HELICAL GEAR
(*By courtesy of David Brown & Sons (Hudd.) Ltd.*)

balls running in grooves, both in the carriage K and the seating block L, the grooves being cut accurately parallel to the ground face of the reference face B. The carriage is anchored to L by means of a light spring in tension, and when the instrument is in use, this spring also holds the stylus point against the face of the tooth being checked.

The stylus end is of conical form, the base being accurately located in the same plane as the reference face B. This location is obtained by means of a cast-iron angle bracket N, in conjunction with a feeler piece O. The conical form of the stylus point ensures that the gauging point always lies in the plane of the reference plane B, whilst by slightly rotating it, a new point on the gauging knife edge can be brought into action in the event of wear having taken place.

Chapter XII

PRECISION MEASURING TOOLS AND MACHINES

Block or Slip Gauges (Fig. 146)

THESE gauges were introduced by E. C. Johannson, and were only obtainable for many years from Sweden. They are now, however, manufactured by several firms specialising in high-precision tool making. The " Matrix " gauges of similar type have come into prominence, and are obtainable from The Coventry Gauge and Tool Co., Ltd.

A full set comprises 81 blocks, each a steel rectangular block with its

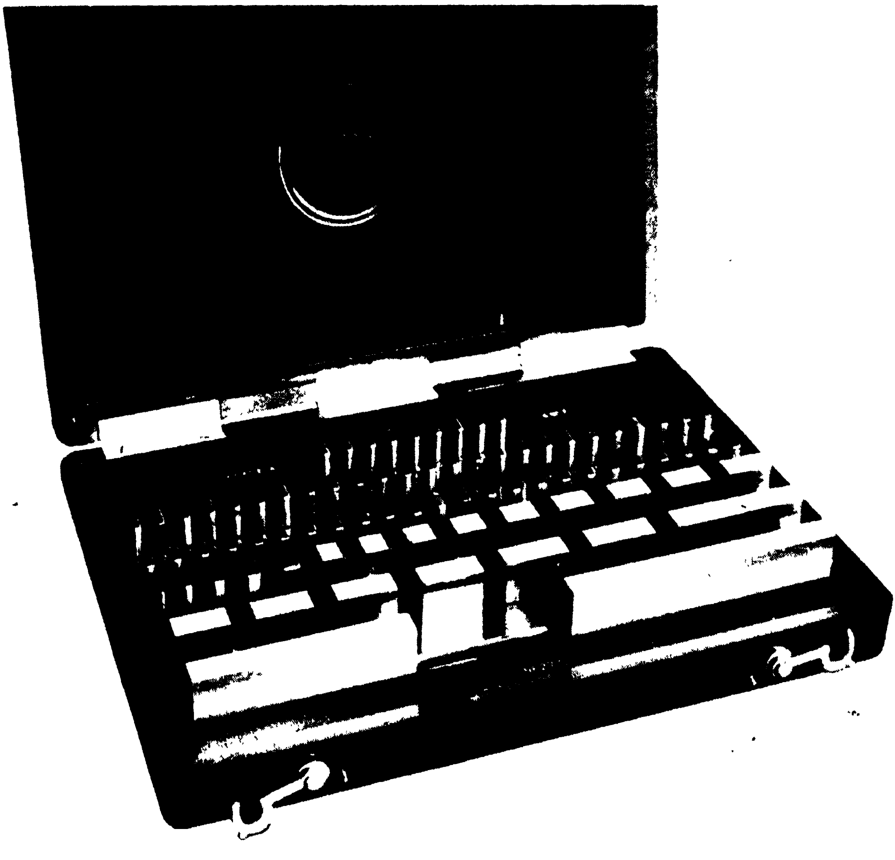


Fig. 146.—" MATRIX " BLOCK OR SLIP GAUGES
(*By courtesy of The Coventry Gauge and Tool Co., Ltd.*)

opposite faces lapped accurately flat and parallel. The degree of accuracy obtained is such that the overall thickness of two gauges wrung together varies by not more than half a millionth of an inch. Any number of these blocks can be wrung together to give the required measurement by means of a slight pressure and a twisting movement. Blocks must never be forced apart; to do this would require a force of approximately 70 lb. for each square inch of contacting area. Wrung blocks should never be left in this state for longer than is necessary, as they tend to adhere more firmly the longer they are left. Before attempting to wring the blocks together, they should be first cleaned with a petrol-moistened cloth, and finally polished with a chamois leather. Any obstruction between the gauges will cause damage to the surfaces.

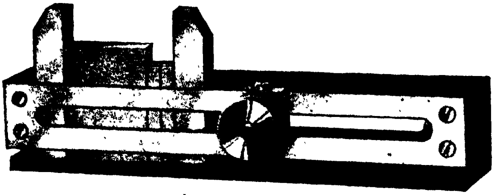


Fig. 147.—MASTER GAP GAUGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

A standard set of 81 Johannson blocks is divided into four series, giving any measurement between ·2 in. and 5 in. in steps of $\frac{1}{10000}$ in. The series are:

(1)	9 gauges	·1001 in. to	·1009 in.,	increasing by	·0001 in.
(2)	49 gauges	·1010 in. to	·1490 in.,	increasing by	·001 in.
(3)	19 gauges	·0500 in. to	·9500 in.,	increasing by	·050 in.
(4)	4 gauges	1·0000 in. to	4·0000 in.,	increasing by	1·000 in.

Combinations of blocks can be wrung together to give any required dimension within the range of the set. Thus, to obtain various dimensions, combinations can be made up as follows:

4·3251	·8754
·1001	·1004
·1250	·1450
·1000	·1300
4·0000	·5000
4·3251 in.	·8754 in.

To ensure that the accuracy of the blocks is maintained during comparison or gauging, the inspection-room temperature should be about 68° F.

Sets of blocks are obtainable for Metric measurements.

Whilst blocks are used primarily as a standard from

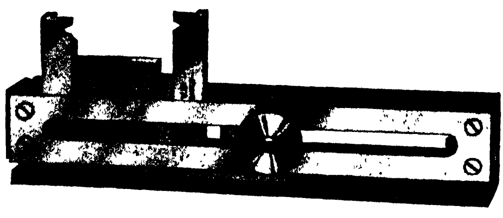


Fig. 148.—MASTER THREAD GAUGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

which measurements are taken or by which various gauges are checked, they can be conveniently arranged in the form of temporary gap gauges. Fig. 147 shows a master gap gauge set up with blocks having a special frame, together with special jaws. A similar arrangement is shown in Fig. 148, and is employed for constructing master-thread gauges. The jaws are notched according to the thread form, 55° for Whitworth threads, etc.

MEASURING MACHINES

The interchangeability and fine limits demanded for components to meet modern production requirements can only be controlled by means

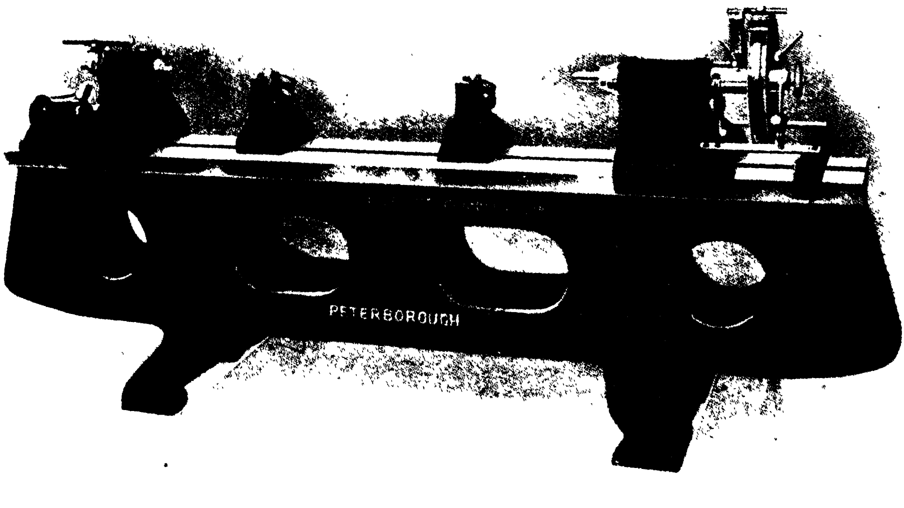


Fig. 149.—MEASURING MACHINE—CAPACITY 0–24 IN. OR 0–600 MM.
(*By courtesy of The Newall Engineering Co., Ltd.*)

of accurate tools and gauges. To achieve the standard necessary, tools, gauges, and fine limits are satisfactorily measured and checked by means of various types of measuring machines. Many reliable machines are at present being manufactured, of which the Newall measuring machine can be taken as a typical example.

The Newall Measuring Machine (Figs. 149, 150)

The construction of the machine is similar to a lathe, the bed, headstock, and tailstock being made of cast iron of hollow section, to allow free circulation of air. The bed rests on three points to prevent distortion, and being of beam section, the true surface is maintained.

THE HEADSTOCK carries the complete measuring screw and nut assembly.

THE MEASURING SCREW is provided with a buttress form thread, cut specially deep to give ample wearing surface, with a range of 1 in. or 25 mm., according to the measurement being taken in either English or Metric. The pitch of the screw is guaranteed correct within $\frac{1}{20000}$ in. (·00005 in.) for English machines, and $\frac{1}{800}$ mm. (·00125 mm.) for Metric machines. The thread portions of the screw and its nut are equal, of

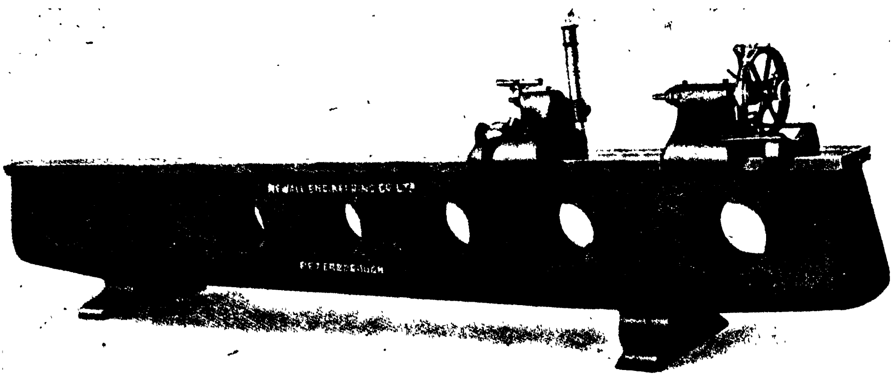


Fig. 150.—MEASURING MACHINE—CAPACITY 0–72 IN. OR 0–1800 MM.
(*By courtesy of The Newall Engineering Co., Ltd.*)

not less than three times the length of the travel of the screw, and the wear being constant, the accuracy of the pitch is maintained. The screw is supported on its plain cylindrical parts at the front, and at the rear in hardened steel bearings to minimise the amount of wear on the effective portions of the thread. Backlash is abolished by an even, constant tension on the screw, which keeps the effective faces of screw and nut in contact and maintained by an automatic adjustment. A secondary screw of the same pitch as the measuring screw is provided on the rear end of the spindle to compensate for any inaccuracies in the pitch of the measuring screw. Undulations made on the crest of this thread impart at any point, through a lever carrying a roller to the zero line on the vernier, forward or backward movement.

THE TAILSTOCK carries the anvil which operates the indicator, the microscope, and spirit level. To obtain sizes greater than the range

of the measuring screw provides, the tailstock is moved bodily to the left. For fine adjustment an arrangement is attached to the tailstock which gives the necessary movement for setting the microscope.

Roller Setting (Fig. 151).—Where sizes greater than the range of the measuring screw are to be taken, the tailstock is set by means of the microscope sighting on a micro-locator, which rests and positions itself on a series of hardened, ground, and lapped rollers of 1 in. or 25 mm. diameter. These series of rollers are accurate within ± ·00002 in. or ± ·0005 mm.

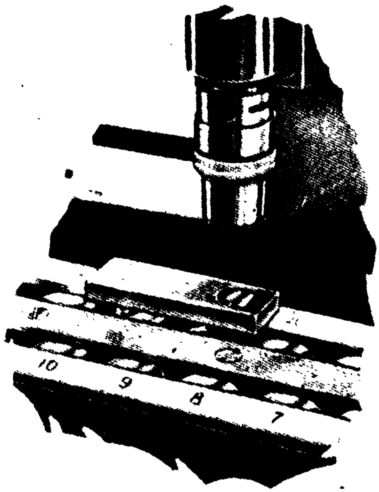


Fig. 151.—Roller setting
(By courtesy of The Newall Engineering Co., Ltd.)

When a machine is not provided with micrometer and roller setting, i.e. for use with standard end measuring rods, a pair of rests for supporting these rods is fitted. The usual design takes standards of $\frac{3}{4}$-in. round section.

Readings.—For English measurement, the machines read to $\frac{1}{100000}$ in. (·00001 in.). The graduations on the measuring wheel are arranged to give the reading in decimals of an inch, the digits appearing in their correct rotation. Reference to Fig. 152 will assist in understanding the method of taking readings. Suppose the reading is ·31254 in., the first digit 3 is the highest figure disclosed on the left-hand side of the scale carrying the vernier, the second and third digits, 1 and 2 respectively, appear as the highest main graduation, and the fourth digit 5 as the highest subdivision on the measuring wheel below, or in front of, the zero line on the vernier, and the fifth digit 4 is that graduation on the vernier in line with any graduation on the measuring wheel.

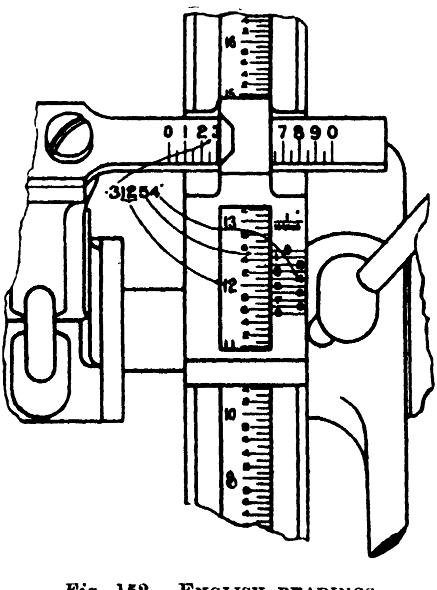


Fig. 152.—English readings

For Metric measurements (Fig. 153), the readings are given to $\frac{1}{10000}$ mm. (·0001 mm.). The scale carrying the vernier is graduated in millimetres, and the decimal parts of a millimetre appear in correct rotation on the graduated wheel and vernier, as for English readings.

The pitch of the measuring screw is 20 T.P.I. for both English and Metric machines, and it is necessary to add ·05000 in. to the indicated size in all cases where the vernier has passed the subdivision between any two main divisions on the scale which carries the vernier. Referring to Fig. 152, if the measuring wheel had been given one complete revolution outwards, the subdivision between digits 3 and 4 on the scale would appear, and the reading would become ·31254 + ·05000 = ·36254 in.

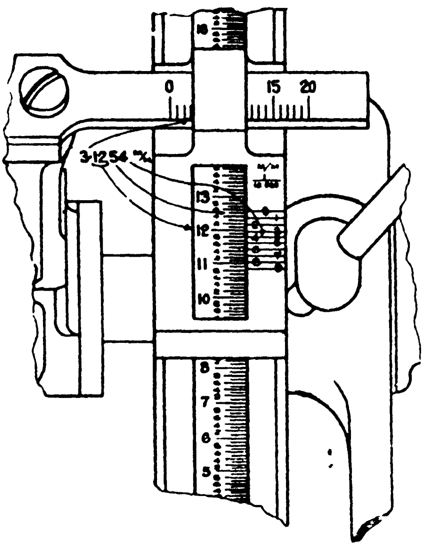


Fig. 153.—Metric readings

The pitch for Metric measuring machines is 1 mm., and all readings are direct as indicated without allowing any additions.

Setting to Zero.—It is first necessary to ascertain the amount of free movement in the anvil ; this is determined by bringing the headstock and tailstock together so that the measuring points make contact, then observing, by forward rotation of the measuring wheel, the number of graduations passed in moving the bubble of the spirit-level indicator from its resting position—right-hand edge against long graduation at left-hand end of vial—to measuring position—with right-hand edge against long graduation at right-hand end of vial. (A small adjusting screw is provided underneath rear of vial for levelling to get the bubble into resting position.) Assuming this free movement to be ·01, either inches or millimetres, the vertical arm carrying the scale and vernier is swung round to a perpendicular position, or inclined a little to the front of the machine if more convenient for the operator's reading, and the measuring wheel set to read about 01. The measuring faces of screw and anvil must be perfectly clean, and the headstock and tailstock securely clamped to the bed. The measuring screw is then advanced until the indicator bubble again reaches measuring position, and the reading will be somewhere near to zero ; it is advisable, however, to release the measuring screw and advance it again to check this final setting, when any slight inaccuracy found may be corrected by readjustment of the vertical arm. The setting

being verified, measurements up to 1 in., or 25 mm. on Metric machines, can be taken.

SETTING TO SIZES OF OVER 1 IN. OR 25 MM.—The tailstock carrying the microscope is moved along the bed to the left ; the headstock is left

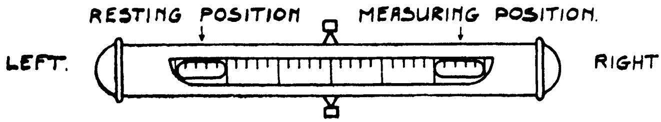


Fig. 154.—SETTING TO ZERO
(*By courtesy of The Newall Engineering Co., Ltd.*)

untouched, and as when finally adjusted to zero. The micro-locator is placed upon the train of rollers, so that the " Vee "-block on its underside rests between those two adjacent rollers which are right and left of that

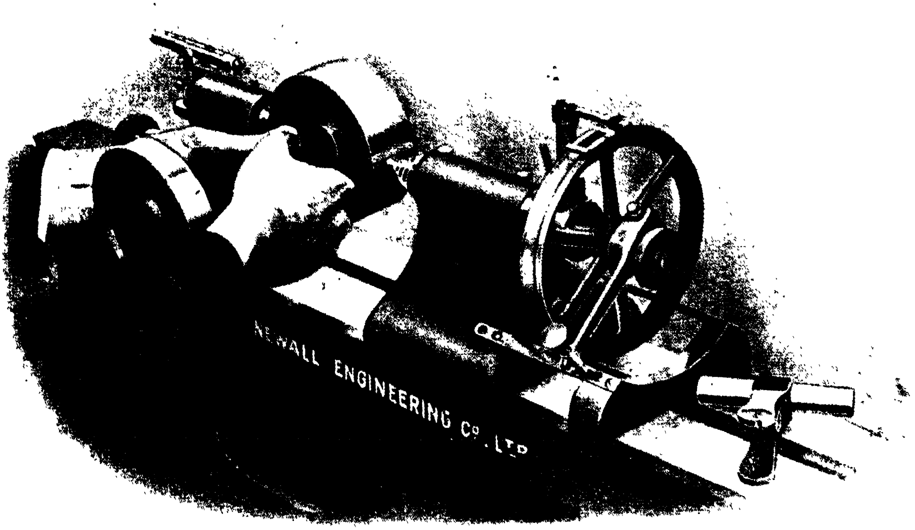


Fig. 155.—SUPPORTING COMPONENT
(*By courtesy of The Newall Engineering Co., Ltd.*)

numbered division (on scale alongside the rollers) which denotes the nearest inch, or 25 mm. below the size to be measured. Position the tailstock so that the microscope centralises with the small window on the micro-locator, and focus the microscope to secure perfect alignment of

its hairline with the needlepoint in the window ; during this operation, the tailstock is only partially clamped, sensitive movement being obtained by means of the fine adjustment provided, while setting. Final clamping is deferred until setting is verified and completed.

In the plain-type machines, without microscope and roller setting, the method of setting for zero over 1 in. or 25 mm. is usually performed with some form of length standard; one of the nearest length under the size to be measured is inserted between the measuring points, and the process, as described in the setting to zero, is repeated. The inaccuracy of such standards must be known, and they should be checked periodically to detect any discrepancies in length due to wear (Fig. 154).

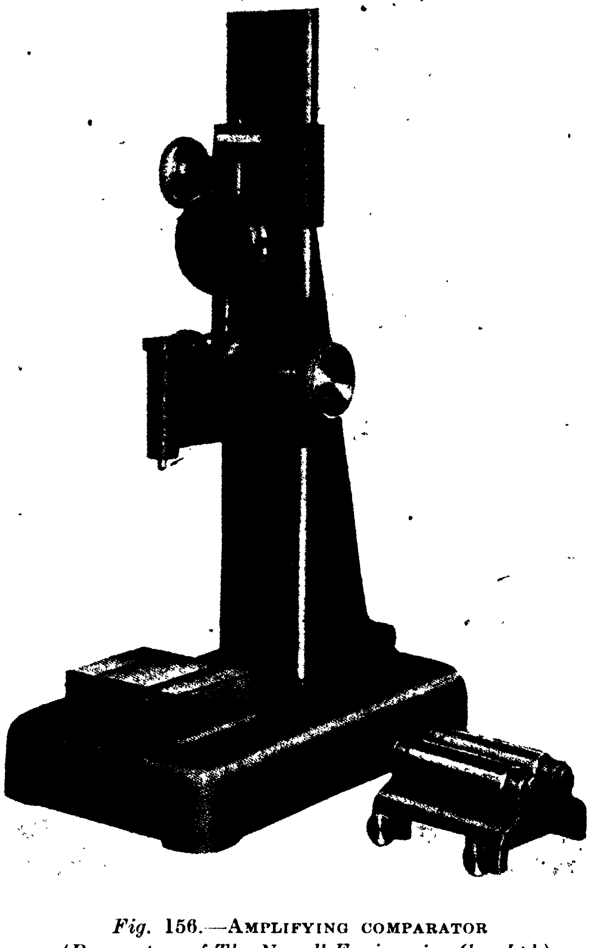


Fig. 156.—AMPLIFYING COMPARATOR
(*By courtesy of The Newall Engineering Co., Ltd.*)

MEASURING.—The component to be tested is held or supported between the measuring points, care being taken to ensure that all points of contact are perfectly clean, and by advancing the measuring screw in precisely the same manner as previously described, and until the bubble of the indicator attains its measuring position, the size of the component is read off the scale, wheel, and vernier as previously explained. When advancing the measuring screw, the knurled nut on the end of the spindle is turned until sufficient pressure has been applied to start the bubble from its resting position, then the fine-adjustment arm is

clamped and its screw brought into use to give slow movement to travel the bubble to its measuring position, the critical point in all operations of setting or measuring. The subdivisions on the vial of the indicator are intended for the purpose of comparisons only, though their approximate value may be determined by observation and calculation if this is desired (Fig. 155).

COMPARATORS

As the name suggests, comparators are used to make comparisons, for checking workshop and inspection gauges against standards. They are very accurate instruments, and somewhat different indicating arrangements have been developed. As there are so many various designs of comparators, of necessity the range considered here must be very limited.

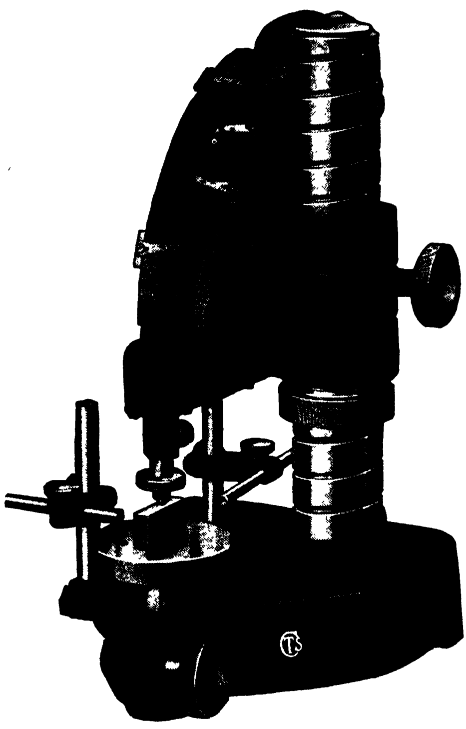


Fig. 157.—" C. T. & S." OPTICAL COMPARATOR
(By courtesy of Cooke, Troughton & Simms Ltd.)

The Newall Amplifying Comparator (Fig. 156)

The column is designed with a rib of buttress form to assure rigidity, and is secured to a heavy base. The main bracket is raised or lowered on the upright column by a small rack and pinion, and carries the indicating dial.

The small bracket over the main bracket allows fine adjustment through a knurled screw and fine screw thread. This is essential for setting the dial to the master gauge.

To obviate any liability of error when taking readings, the dial is amplified through a lever between the registering spindle and the measuring point, permitting readings to be taken to ·0001 in. This measurement appears on the dial face as a $\frac{3}{16}$ in. graduation.

The anvil is attached to the base and equipped with a steel block, hardened and lapped. For checking cylindrical work, a roller-type " Vee " block can be attached to the anvil.

The Cooke, Troughton and Simms Optical Comparator (Fig. 157)

This instrument does not require expert operation, as its accuracy does not depend upon the touch of the inspector. The component is passed under the plunger of the instrument, and the position of the green disc, carrying a line across its centre, observed on a translucent scale.

Direct indication of differences from a standard of ·0001 in., represented by a movement of ·1 in. of the green disc of light, is given. The translucent scale is divided to ·0001 in. over a range of ·006 in., representing a total movement of 6 in. of the green disc.

Two pairs of adjustable indicators are provided to enable work to be graded between two different limits of tolerance.

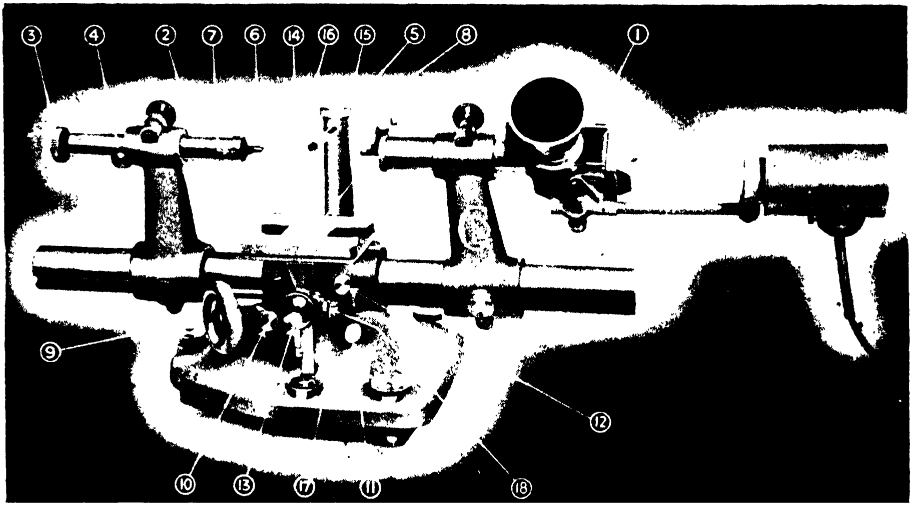


Fig. 158.—THE COOKE HORIZONTAL COMPARATOR
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

The movement of the disc of light corresponds to 1,000 times the movement of the plunger, and this magnification is achieved by means of a combination of optical and mechanical levers.

Components can be tested up to 6 in. high.

The green disc is illuminated by means of a 4-volt lamp, and the instrument can be used on A.C. mains of 200–250 volts by incorporating a transformer, or alternatively by using a dry cell or accumulator of that voltage.

The Cooke Horizontal Comparator (Fig. 158)

The foremost uses of the Cooke horizontal comparator are the verification of diameter, roundness, and parallelism of plug and ring gauges. Apart from these uses, it is equally well adapted for use with rectangular

gauges and similar parts. Attachments are also provided for the determination of roundness and parallelism of both male and female screw-thread gauges, and of pitch diameter.

Measurements, which are indicated by the opticator, are made in the horizontal plane, between a fixed point and one whose movement is recorded by the opticator. Therefore, the work under comparison must be mounted on a table having one or more movements of complete freedom, in order that the very small force exerted by the opticator plunger, which is 7 to 8 oz., shall maintain the work in contact with the fixed point.

Comparison must be made along a common axis of measurement,

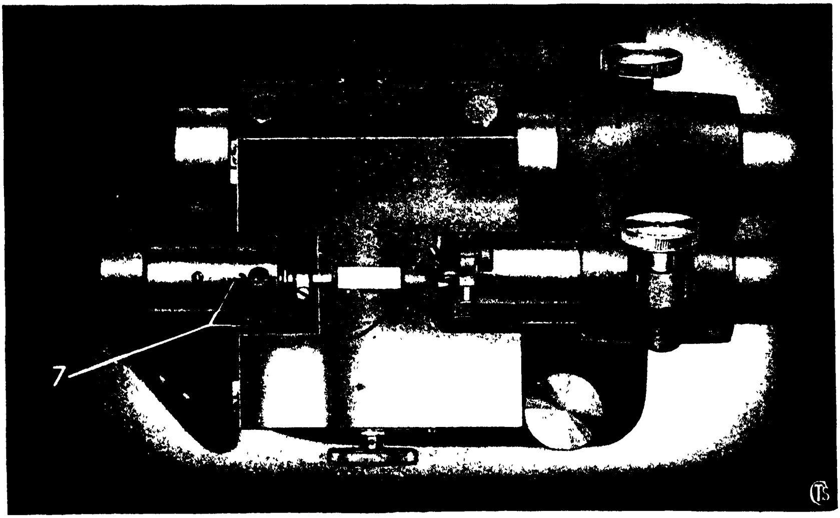


Fig. 159.—GAUGE BLOCK SQUARED-ON IN HORIZONTAL PLANE

(*By courtesy of Cooke, Troughton & Simms Ltd.*)

which is the shortest distance between the two contact tips. Therefore, both master gauge and the component to be compared must in turn be squared on to the axis. The work tables are provided with all the various movements required for this purpose, and the opticator itself is used for facilitating these adjustments preparatory to the determination of actual measurements.

Fig. 159 shows the gauge block squared-on in the horizontal plane, by swinging it about the tailstock centre, as indicated by the arrows in the illustration, to the point where the opticator reading reverses. Although this adjustment can be easily made by hand, care must be taken not to heat up the gauge block by excessive handling.

Fig. 160 shows the similar procedure for squaring the block on the vertical plane, by using the table tilting adjustment (13).

The adjustment necessary to align the contact tips is effected by the tailstock lateral adjusting screws (7). Each screw in turn is revolved until a reversal on the opticator is obtained. After this adjustment, it is advisable to check the squaring-on adjustment of the gauge block as previously explained.

Upon substituting the component for comparison, the procedure illustrated in Figs. 159 and 160 must be repeated.

The correct adjustment is indicated at the point at which the opticator reading reverses, and this principle is employed in all the various applications of the instrument.

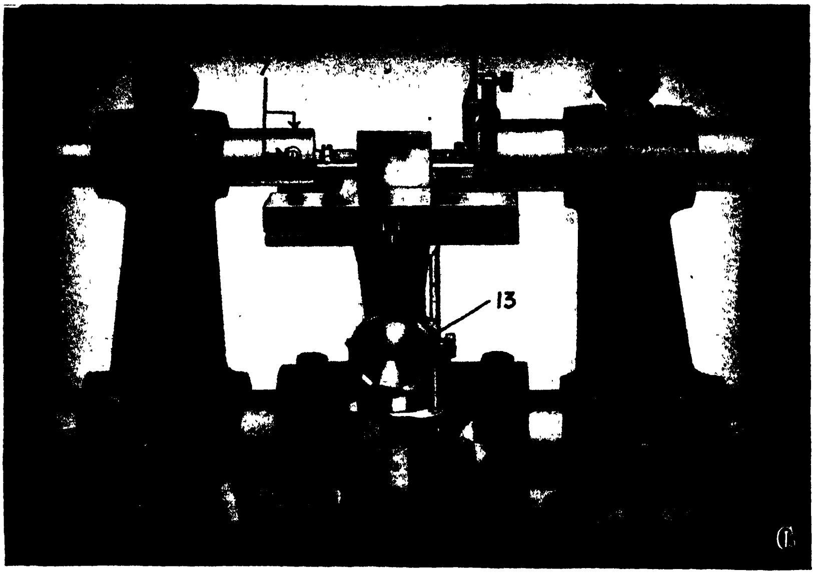


Fig. 160.—GAUGE BLOCK SQUARED-ON IN VERTICAL PLANE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

Description of the Comparator

THE STAND consists of a cast-iron base supported on three levelling screws, and provided with a circular spirit level incorporated in the casting. To the base is attached a cylindrical bed, and brackets carrying respectively the opticator and tailstock are mounted thereon, and are capable of adjustment along the bed.

THE TAILSTOCK is provided with a fine longitudinal adjustment, which serves as a zero setting screw (3), and a clamp to fix this screw (4). For squaring on the tailstock tip (6) with the opticator tip (5), two transverse adjustments (7) set at right angles to one another are provided at the work end.

Three tables supported from the main casting of the instrument give the various movements necessary for aligning the parts under test with the axis of measurement. Two subsidiary tables A and B fit over the main table, the latter being permanently attached to the instrument. The table surfaces are optically worked; the free movements of the tables in each case are facilitated by balls running in heat-treated races. Tables A and B are provided with tapped holes over their surfaces for attachment of holding-down clamps. Vertical and horizontal cradles are provided for holding parts between centres.

THE MAIN TABLE (14) is of " H " plan, measuring 4·5 in. × 4·5 in., permitting the measurement of dimensions down to ·25 in., with the supporting surface ·3 in. below the axis of measurement. The vertical

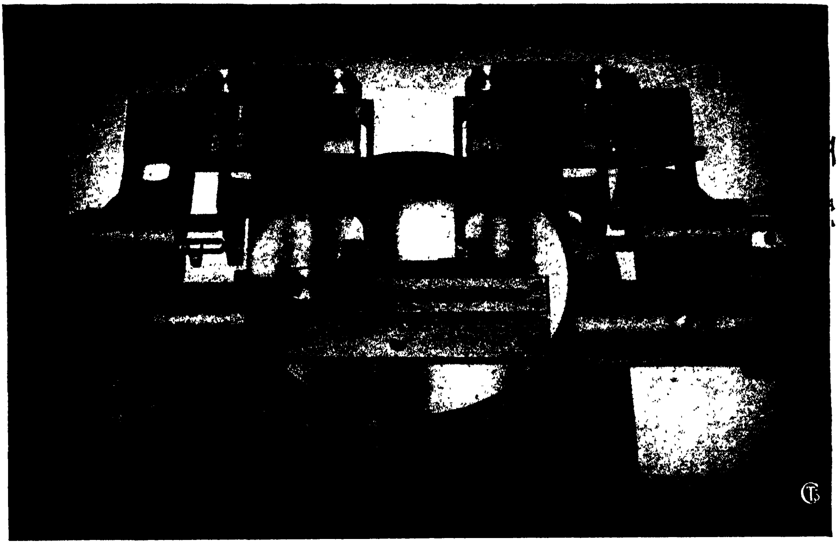


Fig. 161.—PAIR OF FRAMES CARRYING TIPS FOR INTERNAL MEASUREMENT
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

adjustment is actuated by the wheel (9), and at the lowest position the surface of the table is 3·75 in. beneath the axis of measurement. This adjustment is fixed by a clamp (10), and adjustable stops (11 and 12) limit the movement. The head (13) controls a table tilting adjustment in the longitudinal plane of ± 5°, and the free movement in the longitudinal direction has ·4 in. run.

When setting up the instrument it is necessary to position the work on the table and the measuring elements so that there is sufficient run of the free motion available to cover the range of measurement to be made.

To assist this, marks (15) are engraved on the side of the table to indicate the position of the table with reference to the run.

Table A, measuring 7 in. × 4·6 in., has a movement about a vertical axis controlled by a lever (19) (Fig. 166), and limited to $\pm 7\frac{1}{2}°$; above is a transverse movement of ·6 in. actuated by a rack and pinion (20), and uppermost, a longitudinal free movement of ·4 in. The attachment of this table automatically locks the free motion of the main table. Part of the table surface is machined away in order that the remaining optically-worked surface may be brought up to the axis of measurement.

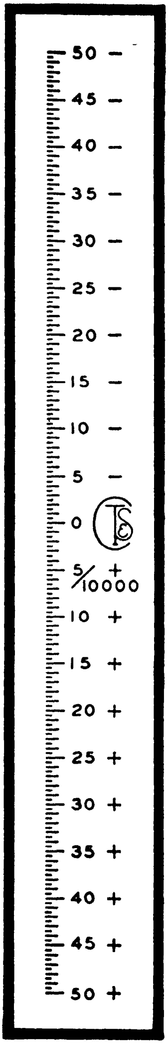
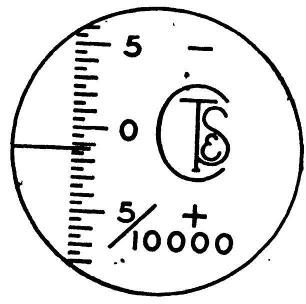


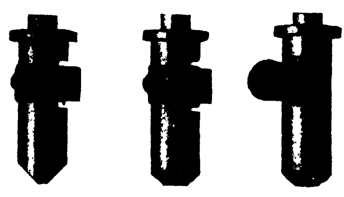
Table B combines a free transverse movement of ·5 in. with a free circular movement about a vertical axis, and works in conjunction with the free longitudinal movement of the main table.

Cradles C and D.—For holding parts between centres, two cradles are provided. Cradle C is used in conjunction with Table A, and holds work between horizontal centres, the maximum distance between centres being 6 in. Cradle D is used on the main table for holding work between vertical centres, the maximum centre distance being 7 in. When using wires for measuring fine threads, Cradle C is generally more convenient, as the wires can be suspended from above. When testing parallelism of cylinders, Cradle D, in conjunction with the vertical movement (9), is very convenient.

The detachable graduated work fence (16) can be removed when desired.



Field of View
Reading shown = +0·000125″



Opticator Contact Tips
Knife Edge Plane Spherical

Fig. 162. Opticator scale, field of view and contact tips
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

Contact Tips, two spherical, two plane, and one knife edge, are the normal equipment for external measurement for attachment direct to

the opticator and tailstock, the knife-edge tip being necessary when three wires are employed for thread measurement.

Spherical tips of suitable radius are supplied for internal measurement of plane surfaces.

Hyperspherical tips of such radius that they will contact with the thread approximately on the pitch diameter are used for internal thread measurement.

The contacting tips for all internal measurements must face away from one another, and it is therefore necessary to interpose some mechanism

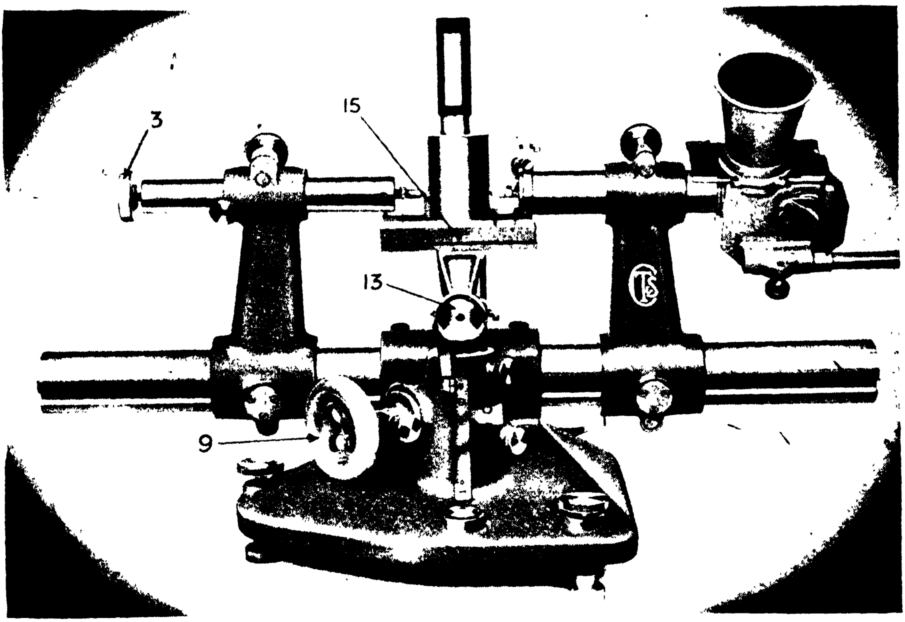


Fig. 163.—CHECKING A PLUG GAUGE
(By courtesy of Cooke, Troughton & Simms Ltd.)

between the tips contacting with the work and the opticator and tailstock tips respectively (see Fig. 161).

Opticator (Fig. 162)

The opticator has a minimum of one moving element, i.e. the plunger which contacts the work, and the mirror associated with it. The remainder of the system is entirely optical and therefore unaffected by friction or other mechanical defects. Light from the illuminating unit is admitted through a rectangular aperture in the side of the instrument, and after passing through a scale engraved on glass, reaches a mirror at the contact end of the instrument, from whence it is returned to a trans-

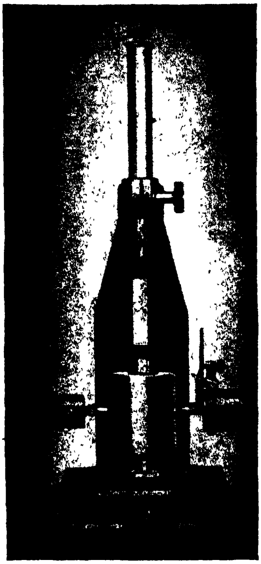


Fig. 164.—WORK FENCE IN POSITION

(*By courtesy of Cooke, Troughton & Simms Ltd.*)

lucent screen contained within a hood, a magnified image of the scale being formed on the screen as shown. The plunger contacting the work controls the movement of the mirror and therefore the position of the image of the scale on the screen with reference to the index.

The total magnification of the movement of the plunger registered on the screen is approximately $\times$ 1,000, that is, a movement of the plunger of ·001 in. will translate the image of the scale across the screen by 1·0 in. There are twenty divisions contained within 1·0 in. on the screen ; thus, one division of the projected image of the scale corresponds to ·00005 in. movement of the plunger. It is convenient to estimate readings to one-fifth of a division, which is $\frac{1}{100,000}$ in. The overall length of the scale image represents a movement of the plunger of ·01 in., or $\pm$ ·005 in.

A lantern with optical condensing system is attached to the opticator, and can be operated from a 220/250-12-volt transformer.

Adjustable colour screens are provided for indicating tolerances.

Methods of Checking

(1) *To determine the Diameter and check Parallelism and Roundness of a Plug Gauge* (Fig. 163)

The equipment required consists of plane tips and main table only.

First select and wring together slip gauges corresponding to the nominal size. Ensure that the gauge on the table and the opticator and tailstock are so positioned that there is sufficient free run of the table to cover the differences to be measured. Indicating marks (15) facilitate this. This point must be watched in all applications of this instrument. The opticator is set to zero by screw (3), and next, square on gauge in vertical and horizontal planes and align tailstock tip, as previously described. Now reset the opticator to zero. The gauge block is now removed and the plug entered until the maximum opticator reading is reached. This indicates that the measurement is across a diameter. Verify that the plug is at a normal to the axis of measurement by tilting the table (13).

The reading now given by the opticator is the difference between the length of gauge block and the diameter of the plug gauge at the section under test. To check for parallelism, raise or lower the table by means

of the large wheel at the base of the instrument (9). It is advisable at each stage to retest that the plug remains normal to the axis of measurement. For repetition testing the limit stops are used.

A plug gaúge can be tested for roundness by carrying out the same procedure across different diameters, and the use of the work fence will facilitate this. The plug gauge generally having true centre bearings, it is convenient to use either the vertical or horizontal cradle and Table A, and to revolve the gauge with the opticator in action (Fig. 164).

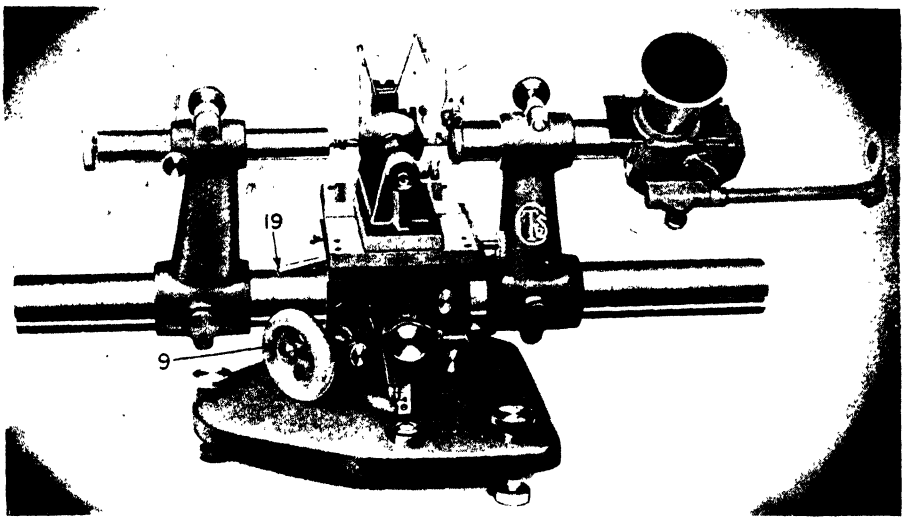


Fig. 165.—CHECKING A MALE SCREW GAUGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

(2) *To determine the Pitch Diameter and check Parallelism of a Male Screw Gauge* (Fig. 165)

The equipment required consists of Table A, horizontal Cradle C, needles appropriate to the pitch of the thread, plane tip in the opticator and knife-edge tip in the tailstock with its axis horizontal.

The procedure is the same as in the previous example up to the point of resetting the opticator to zero. This is followed by placing the screw gauge in the horizontal cradle and mounting on Table A. One needle is now inserted between the gauge and plane opticator tip, and two needles between the gauge and knife-edge tip of the tailstock, and in such a manner that the three needles form an isosceles triangle. The gauge is squared on to the axis of measurement by the horizontal circular motion (**19**), and assuring measurement is across the diameter by employing the vertical motion (**9**).

The reading given by the opticator is the difference of the measure-

ment over the needles as compared with the gauge block used, from which can be determined the pitch diameter by formula in the usual manner. The parallelism and roundness of the gauge can be tested by determining the pitch diameter over different portions of the gauge.

(3) *To determine the Diameter, Parallelism and Roundness of a Ring Gauge* (Fig. 166)

The equipment required consists of Table A with work clamp if the gauge is a light one, plane tips in both opticator and tailstock, normal

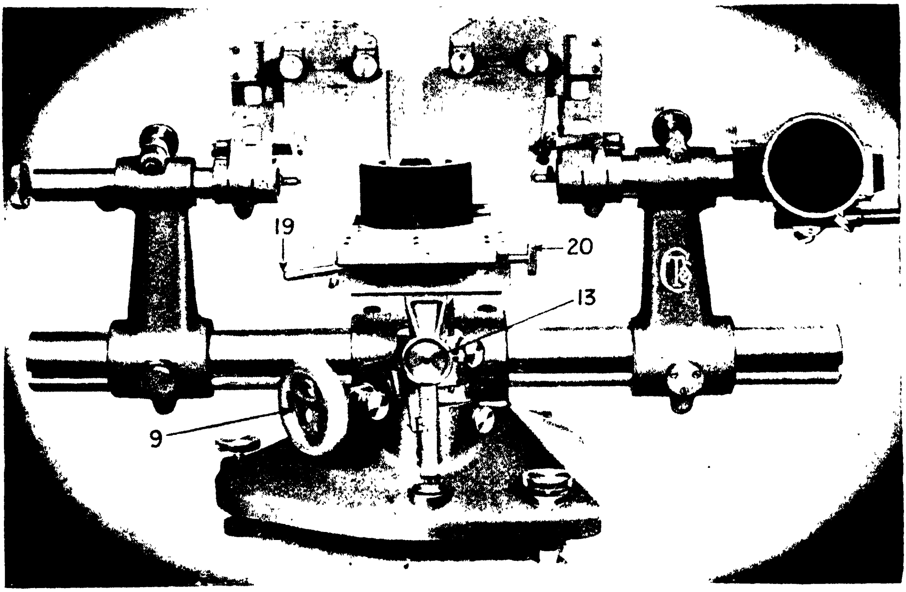


Fig. 166.—Checking a ring gauge
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

frames set vertically with spherical tips contacting with the work, and composite gauge frame, gauges, and plane jaws (Fig. 167).

First, the plane tips are squared on opticator and tailstock. In this case, this must be done by bringing the tips in contact with one another by sliding the brackets along the base. Adjustment is secured by obtaining minimum reading in two planes by the tailstock lateral adjusting screws (7). Next, construct composite gauge to nominal dimension and place in position. Now set the opticator to zero, square on composite gauge by circular motion (19) and tilting adjustment (13), and reset to zero. The ring gauge is now placed in position, and, if light, clamp to table, square on in vertical plane by screw (13), and set the diameter in plane of measurement by traverse screw (20), when the opticator will

indicate the departure of the ring gauge from the gauge blocks. To test for roundness, repeat across different diameters, and for parallelism raise or lower the table by the wheel (9).

The Cooke Works Measuring Microscope (Fig. 168)

The works measuring microscope is made to cover a wide range of applications, including the examination of opaque and translucent specimens, and profile forms. A large range of microscopes is available, and produced by well-known optical instrument manufacturers, of which the Cooke Works Measuring Microscope is selected as typical, and produced by Messrs. Cooke, Troughton and Simms Ltd.

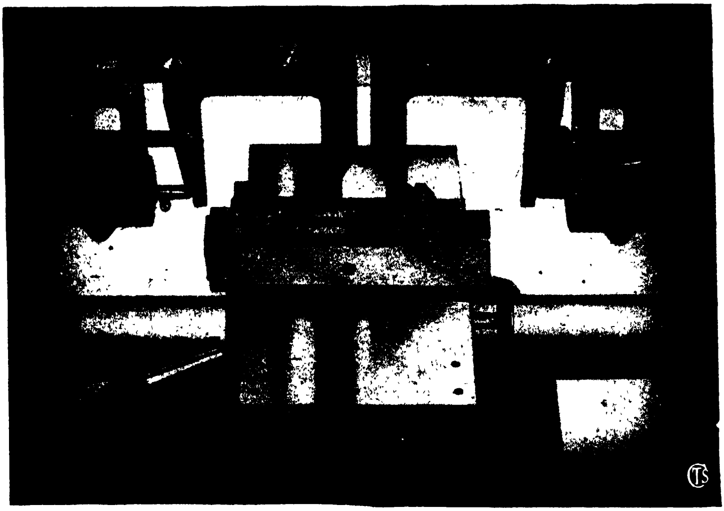


Fig. 167.—SQUARING ON COMPOSITE GAUGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

DESCRIPTION.—A feature of this instrument is the lighting system, incorporated in the body tube for the illumination of opaque objects, Brinell impressions, and surface examination. The liability of shadow effects interfering with accurate measurement is obviated by the fact that the light reaches the object from a direction co-axial with the line of sight.

THE STAND is of horseshoe form, having three flat surfaces and two "Vee" surfaces on the underside, allowing the microscope to be used on a surface plate or cylindrical surface. Three studs for carrying the interchangeable stages are provided on the top side of the base plate.

The Vertical Pillar carrying the micrometer traversing mechanism and microscope is telescopic, and provided with the necessary clamp. When the clamp is released, the weight of the microscope is taken by a

spring, thus preventing it from falling on to the base. The microscope is adjustable, and can be lowered to bring within the focusing range the surface on which the base stands, whilst allowing parts 3 in. high to be accommodated on the plain stage.

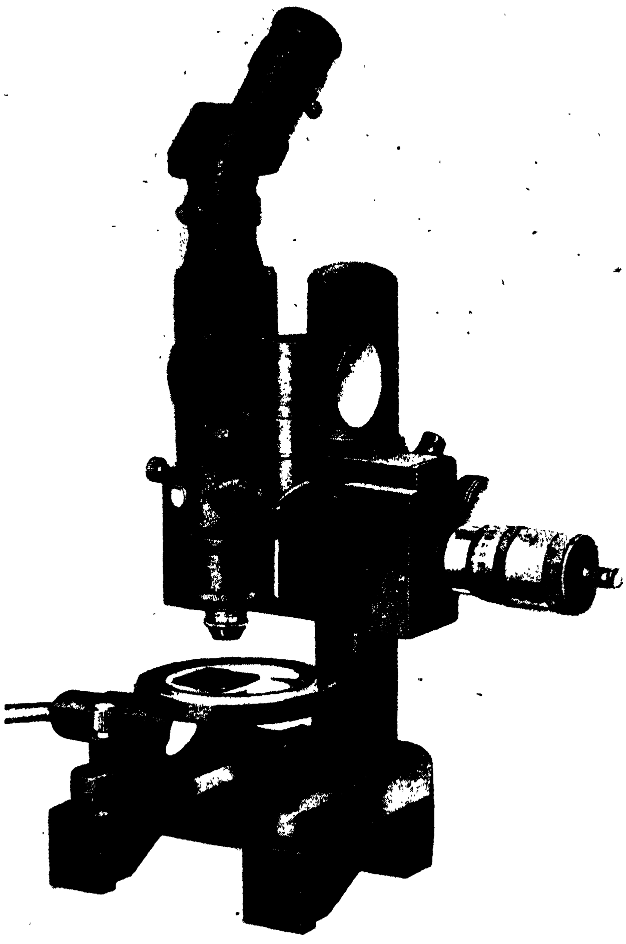


Fig. 168.—THE COOKE WORKS MEASURING MICROSCOPE (*By courtesy of Cooke, Troughton & Simms Ltd.*)

The Travelling Mechanism. — The microscope is mounted on a ball-bearing slide which allows free and consistent movement. The movement is actuated by a micrometer screw with a range of 1 in., and a pitch of 40 T.P.I. The drum is divided into 125 parts, of which one division corresponds to a movement of ·0002 in.

The Body Tube can be fitted with an inclined eyepiece attachment which is reversible, and allows the work side of the microscope to be placed away from the observer when using daylight illumination. The eyepiece is fitted with cross wires which can be focused independently to suit the observer's eye, and can be used in conjunction with the micrometer when making measurements. It is obvious that, under these conditions, the eyepiece must be fixed rigidly to the body tube, and therefore clamps are provided for this purpose, both to the eyepiece and the inclined attachment. Focusing is by rack and pinion, operated by milled heads on either side of

the tube. An achromatic objective, $\frac{2}{3}$ in. focal length, is included in the standard equipment.

The Vertical Illuminator consists of a glass plate reflector, together with a built-in light source. The illuminant is fitted with an iris diaphragm for the control of light intensity, and a second iris for the regulation of the illuminated area of specimen. The lamp is for 4-volt supply, and a transformer is available for use on 220/250-volt circuits.

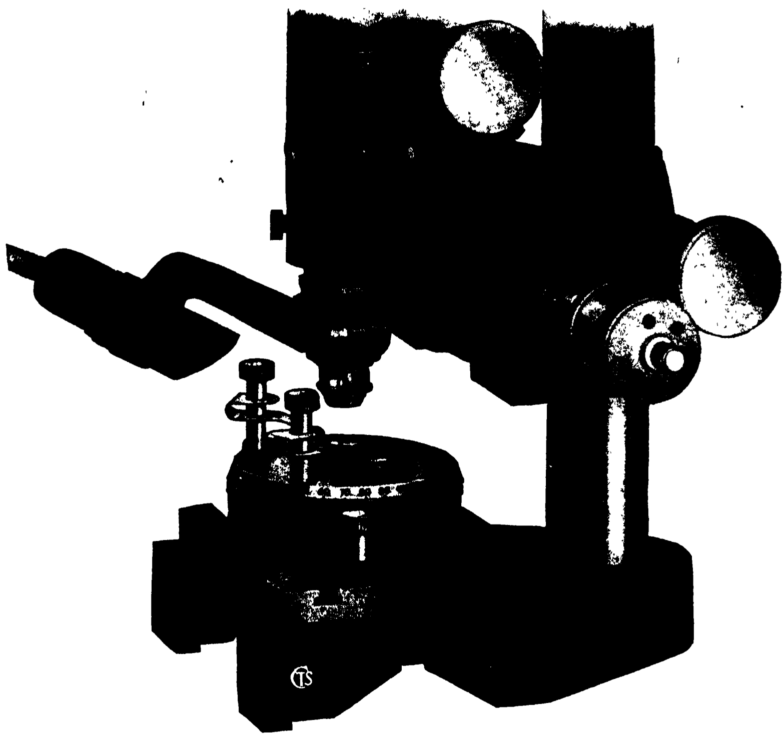


Fig. 169.—CIRCULAR MEASURING STAGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

Oblique Illumination can be arranged by transferring the lamp fitting to the bracket at the base of the microscope body.

For Opaque Specimens a steel object stage 4 in. × 3 in. is employed, having two spring clips mounted in a machined groove.

A Circular Measuring Stage can be mounted on the plain stage, and is graduated in degrees. Apart from the measuring of angles, this stage is used in setting parallel to the measuring slide the work to be measured (Fig. 169).

The Stage for Transmitted Light is of circular design, fitted with a glass disc and capable of rotation. A bayonet fitting is provided to receive the lamp from the body tube.

Optical Data.—The following data relates to three objectives provided. It will be noted that the data varies according to whether or not the inclined eyepiece attachment is used. This is due to the variation in effective tube length occasioned by the insertion of the fitting in the optical train.

OPTICAL DATA

Objective	*With Standard Body Tube*			*With Inclined Eyepiece*		
	Magnification with × 6 *Eyepiece*	*Field of View*	*Working Distance*	*Magnification with* × 6 *Eyepiece*	*Field of View*	*Working Distance*
$\frac{5}{8}$ in. (16 mm.)	× 40	·078 in. (2 mm.)	·265 in. (6·79 mm.)	× 64	·058 in. (1·5 mm.)	·2 in. (5·13 mm.)
1 in. (25 mm.)	× 24	·156 in. (4 mm.)	·65 in. (16·66 mm.)	× 40	·094 in. (2·4 mm.)	·6 in. (15·38 mm.)
$1\frac{1}{3}$ in. (33 mm.)	× 15	·234 in. (6 mm.)	1·65 in. (42·31 mm.)	× 27	·136 in. (3·5 mm.)	1·5 in. (38·46 mm.)

The Vickers Contour Projector (Fig. 170)

The optical projection method of checking components is now widely used in many inspection departments. Especially is this method of particular utility for inspection of screw-thread and gear-tooth profiles ; it also enables comparisons tó be made with the images of standard shapes. The projector shows an enlarged image, or outline of the component under test, which bears a definite scale relationship to the original.

The design of the instrument is such that the object and image planes are close together, and all controls can be manipulated whilst the image is under observation. Since projection is from beneath the screen, this apparatus has the advantage that the inspector does not tend to produce shadows across the projected image when taking measurements with a rule or protractor.

The illumination is sufficient to allow the use of the projector in a well-lighted room, whilst when necessary a hood can be used to cut off any stray light from the screen.

The size of the projected image bears a fixed relationship to that of the object, i.e. exactly 10, 25, or 50 times.

The dimensions of the component under test can be determined in two ways :

(1) By measuring the projected image and dividing the result by the appropriate magnification factor.

(2) By translating the projected image in relation to a fiducial line on the projection screen, and by noting, on the micrometer screws of the

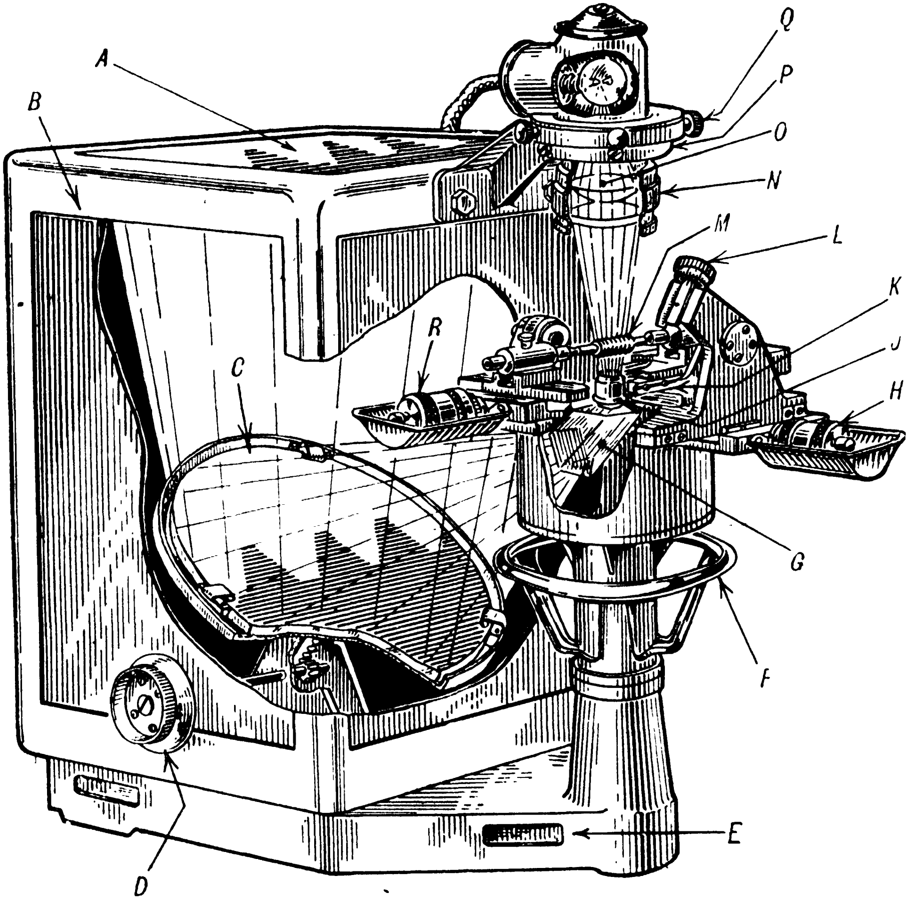


Fig. 170.—VICKERS CONTOUR PROJECTOR

A Projection Screen.
B Camera.
C Mirror.
D Adjustment for Magnification.
E Cast Iron Base.
F Focusing Wheel.
G Roof Prism.
H Transverse Micrometer.
J Projection Anastigmat.
K Ball Bearing Slides.
L Helix Angle Micrometer.
M Screw Thread under test.
N Condenser Spiral Focusing Sleeve.
O Condenser.
P Centring Screws for Condenser.
Q Centring Screws for Lamp.
R Longitudinal Micrometer.

(*By courtesy of Cooke, Troughton & Simms Ltd.*)

measuring stage, the value of the movements necessary to bring this about.

In the first method, measurement of the image can be conveniently made with a glass scale, or from a template made to the appropriate scale. Such templates can be made photographically from a master component drawn on tracing paper, or formed from sheet metal.

GENERAL DESCRIPTION

The Base is made of cast iron, carrying the camera box and the pillar incorporating the focusing mechanism, and supporting the measuring stage and prism box.

The Camera Box is a cast aluminium frame, having sheet-metal panels. The ground-glass projection screen is mounted in the top surface.

The Lamp Bracket and Box carries the lamp and condensing system, and is provided with means of centring the light in the optical axis.

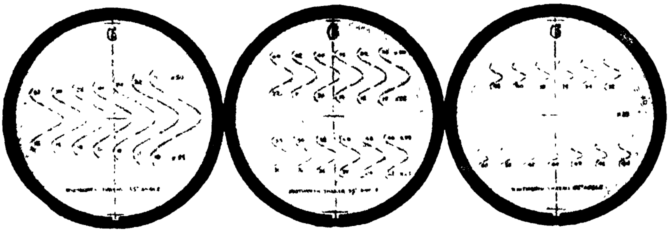


Fig. 171.—WHITWORTH THREAD TEMPLATES 55°

(*By courtesy of Cooke, Troughton & Simms Ltd.*)

The Lighting Unit for Alternating Current.—This consists of a low-voltage filament lamp (8 v. 6 amp. 100 c.p.) and transformer. For use with direct current, a Pointolite lamp with ionising switch and resistances is used.

The Condensing System.—Two alternative focusing condensers are supplied :

(*a*) To produce a convergent beam for the illumination of the whole area of the ground-glass screen.

(*b*) To produce a parallel beam for the critical projection of thread forms in the centre of the ground-glass screen.

The Mirror is a circular glass approximately 9½ in. diameter, silvered on the upper face and mounted in a metal holder fixed to a rack. This rack is operated by a large knurled-head screw permitting adjustment to yield the exact magnification required with the projection lens in use.

The Focusing Mechanism is incorporated in the pillar, and consists of a large screw operated by handwheel.

The Measuring Stage consists of two slides at right angles, mounted

on ball bearings and controlled by micrometer screws reading to ·0002 in.

The total movement of the transverse slide is 1·5 in.

A total movement of 3·0 in. can be obtained by the use of a special high cradle.

Total movement of longitudinal slide is 2·0 in., and the range of the micrometers is 1·0 in. Standard slip gauges can be used in conjunction with the micrometers.

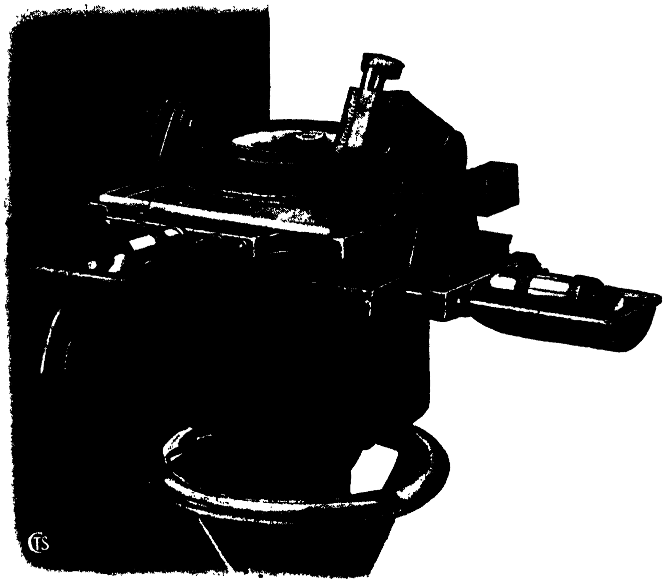


Fig. 172.—LOW CIRCULAR STAGE
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

The stage also has a tilting movement in the longitudinal direction with a range of $\pm$ 10°, and reading by micrometer to 5 mins.

Capacity	*Dia.*	*Max. Length*
With low cradle and $\times$ 50 projection lens	2 in.	5 in.
With high cradle and $\times$ 10 projection lens or $\times$ 25 projection lens + adapter	3 in.	12 in. (depending on dia.)
Working distance of projection lens $\times$ 10		3·4 in.
Working distance of projection lens $\times$ 25		1·12 in.
Working distance of projection lens $\times$ 25 + adapter		1·55 in.
Working distance of projection lens $\times$ 50		·54 in.

The Equipment includes :

Anastigmatic Projection Lens × 10.
Anastigmatic Projection Lens × 25.
Anastigmatic Projection Lens × 50.
Adjustable Low Circular Stage, for use with Projection Lens × 25 or × 50.
Low Cradle, for use with Projection Lens × 25 or × 50.
Adjustable High Circular Stage, for use with Projection Lens × 10 or × 25 + adapter.

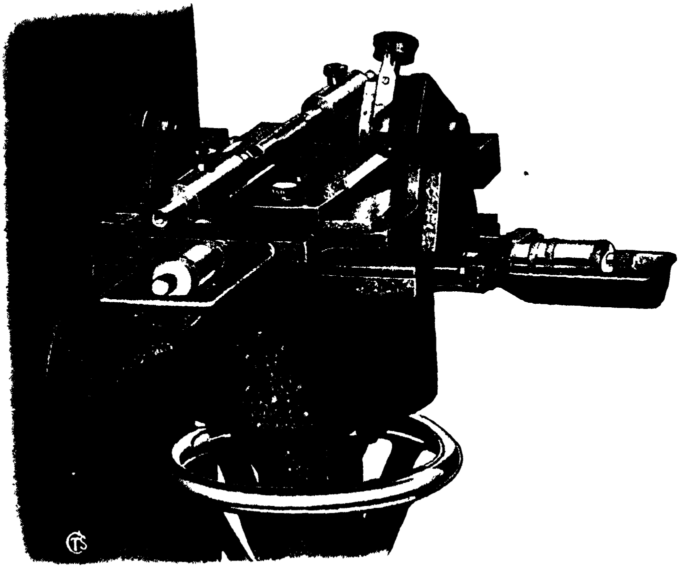


Fig. 173.—Low cradle with thread under test
(*By courtesy of Cooke, Troughton & Simms Ltd.*)

High Cradle, for use with Projection Lens × 10 or × 25 + adapter.
Adapter, for use with Projection Lens × 25, in conjunction with high cradle and high stage.
Magnification Gauge Glass 2 in. long, divided.
Glass Scale, divided into 8 in., with 1-in. divisions subdivided to ·2 in.
Achromatic Magnifier × 5, in stand.
Photographic Focusing Screen, and Single Dark Slide, for plate 10 in. × 8 in.
Green Filter Condenser Attachment for visual observation.
Blue Filter Condenser Attachment for photography.
Thread Template Adapter and Protractor, consisting of metal plate to fit the top of the camera case in place of the ground-glass screen, and equipped with circular protractor reading to 5 mins., with clamp and rotary mechanism.

Whitworth Thread Templates 55° angle (Fig. 171), standard and fine, the set comprising four glass discs, as follows :

Range at × 50 : 12, 13, 14, 15, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 56, and 60 threads per inch.

Range at × 25 : 6, 6·5, 7, 7·5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 56, and 60 threads per inch.

British Association Thread Template, 47½° angle, one glass disc.

Range at × 50 : Nos. 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.

Metric Thread Template, 60° angle, one glass disc.

Range at × 50 : 2, 1·75, 1·5, 1·25, 1, ·75, ·5, and ·25 mm.

Range at × 25 : 4, 3·5, 3, 2·5, 2, 1·5, and ·5 mm.

Fig. 172 shows low circular stage for plane objects.

Fig. 173 shows low cradle with thread under test.

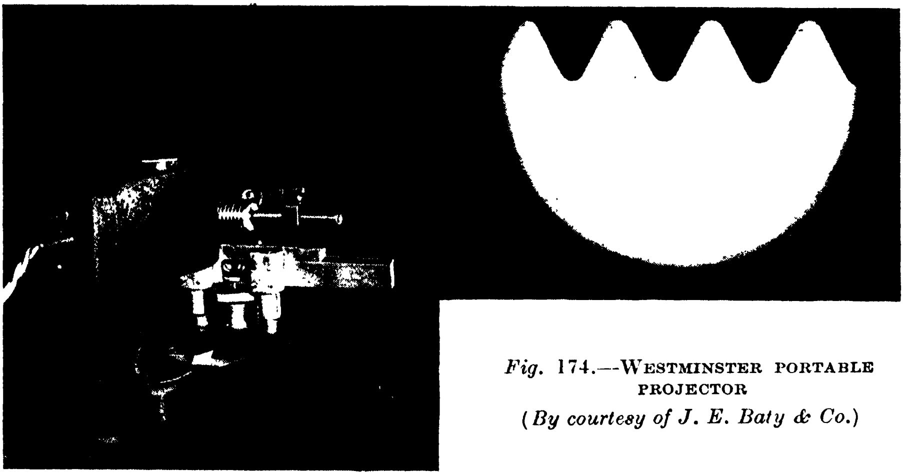


Fig. 174.—WESTMINSTER PORTABLE PROJECTOR

(*By courtesy of J. E. Baty & Co.*)

The Westminister Portable Projector (Fig. 174)

This projector has been introduced by Messrs. J. E. Baty & Co. as suitable for use as a permanent installation in the inspection room, or part of the equipment of a travelling inspector, where work to be inspected is comparatively small, or so infrequent as to prohibit the necessary expenditure for the larger type of projector.

No special screen is necessary with this apparatus, and the image can be thrown on to a wall or a drawing board. Only a small rigid table is necessary to set up the projector, and this can be accomplished in 5 mins.

A dark room is unnecessary for projection providing light, from sources other than the projector, is not allowed to fall directly on the screen.

Capacity of the Westminster Projector

(1) Fifty magnifications with 1-in. lens. Working distance 52 in. from lens to screen. Components up to 1·1 in. diameter and 4 in. in length can be accommodated. Field ·32 in. diameter projects to 16 in. diameter on the screen free from distortion.

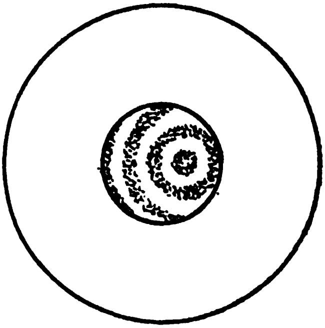


Fig. 175. — Showing micrometer spindle under test and high spot

(2) Twenty-five magnifications with 2-in. lens. Working distance 52 in. from lens to screen. Components up to 1·6 in. diameter and 4 in. in length can be accommodated. Field ·40 in. diameter projected to 10 in. diameter on screen free from distortion. By removing the centre clamps, components up to $2\frac{1}{2}$ in. diameter can be examined by laying them on the "Vees," and projecting the form of the underside.

(3) Fifty magnifications with 2-in. lens. Should it be desired to project larger diameters than 1·1 in., as described in (1), the 2-in. lens can be used and the projector placed twice the distance from lens to the screen, i.e. 104 in. Components up to $2\frac{1}{2}$ in. can then be examined as described in (2).

(4) One hundred magnifications with 1-in. lens. Components up to 1·1 in. diameter can be magnified 100 times at a working distance of 104 in. It must be borne in mind, however, that whilst 100 magnifications may be convenient for some work, the intensity of the illumination of the screen will be only one-quarter of that obtained when using 50 magnifications. Usual practice is to have a crisp outline rather than an increased size. For projecting at 100 magnifications, a dark room is advisable.

Fig. 176A.—Moore and Wright optical flat test for micrometer anvils

Electrical Supply.—The lamp is 6 volts 36 watts capacity, and the standard equipment includes a transformer so that the projector can be run off a lamp socket if the supply is A.C. of 200 or 240 volts. A special transformer is supplied for other voltages. If no A.C. supply is available, the lamp can be run off a 6-volt accumulator.

OPTICAL FLATS.—These consist of cylindrical discs of good-quality, clear, hard ground glass, or quartz, and are obtained singly or in sets of three. The opposite flat surfaces are ground plane and parallel to within limits of ·000005 in., and the thickness to tolerances of ·00001 in. They are used to test for flatness the surfaces of micrometer anvils and spindles and other lapped surfaces. The surface to be tested should be brought as close as possible to the optical flat without a wringing contact being made, when a series of rainbow bands will be observed. These bands are known as "interference bands," and are due to optical interference in the very narrow air gap between the flat and the surface to be tested. The degree of flatness is determined by whether the bands appear curved and irregular or straight and parallel. A high spot is clearly indicated by the centre of the bands, and if the bands appear straight and parallel, the surface is truly flat (Fig. 175). For general mechanical purposes, a surface might be defined as flat when all clearly defined bands have disappeared, but a true surface flatness is not too difficult to obtain.

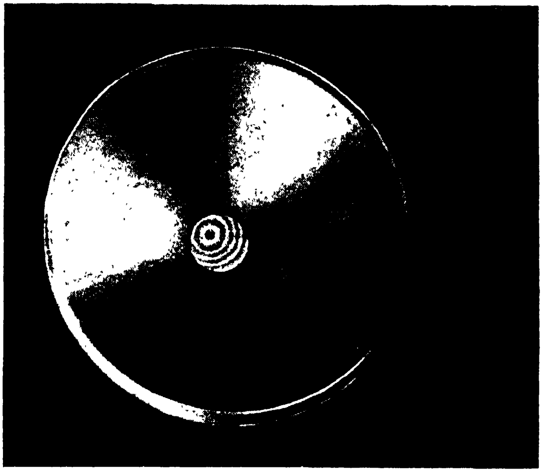


Fig. 176B.—MOORE AND WRIGHT OPTICAL FLAT TEST FOR MICROMETER ANVILS

Figs. 176A and B show the Moore and Wright Optical Flat Test for micrometer anvils of their manufacture. When no bands appear as at (A), the anvil is passed as flat. When the anvil face shows a series of bands as at (B), it is positive evidence that the face deviates from true flatness. The number of bands is in proportion to its inaccuracy. No face is passed as flat which has more than one complete interference band.

The test is best performed under coloured light, as then the bands appear a dark-grey colour.

Chapter XIII

ENGINEERING MATERIALS

Wood

THE different kinds of wood used in engineering practice are, chiefly, ash, beech, boxwood, elm, fir, hornbeam, lignum vitæ, mahogany, oak, pine, spruce, teak, and walnut.

ASH.—After the oak, the ash is probably the most useful timber. Where shocks have to be resisted, it is eminently suitable, as it is straight-grained, tough, elastic, and light in weight. It is used for agricultural implement parts, handles for tools, hammer and axe shafts, and parts of framing for machinery.

BEECH.—Can be used for under-water work, as when totally submerged it will last a considerable time. It also lasts well when kept perfectly dry. It will give a smooth surface, and is used for cogs of mortise wheels and joiners' tools.

BOXWOOD.—Is of yellow colour, heavy, and very hard. It takes on a very smooth surface, and is used for machinery bearings, pulley block sheaves, small rollers, etc.

ELM.—Like the beech, is very durable in damp conditions, and is used for piles and paddle-wheel floats, etc.

FIR AND PINE.—Are largely used for patternmaking.

HORNBEAM.—Is very hard and tough, and is used for making cogs of mortise wheels and parts of agricultural implements.

LIGNUM VITÆ.—Is very hard and compact, and used for making bearings which are submerged in water.

MAHOGANY.—Is a West Indian and South American timber. The true mahogany tree is the *Swietenia*, or Spanish mahogany. The best mahogany comes from the coast of Honduras. It is very strong, straight-grained, and is used for airscrews, veneers of certain plywoods, and packing blocks.

OAK.—Is one of the strongest and most durable woods for either dry or wet conditions.

SPRUCE.—Is soft and light, being known in the trade as "Baltic White Pine." For structural members of a composite aircraft, "Sitka" spruce, from British Columbia, is used.

TEAK.—Is a very tough wood, having a straight but open grain. The best and most extensive forests are found in Burma. It is a very valuable timber, containing an essential oil which renders it almost imperishable,

and preserves the wood from attack by insects. Changes of temperature and moisture have little effect.

WALNUT.—American black walnut is used most extensively for aircraft. It is a very hard wood and dark in colour. It is used for packing blocks and airscrews.

Cast Iron

The basis of the iron industry is the pig iron. The latter is a crude iron which, after smelting from its ore, is run off into channels in moulding sand and allowed to solidify. The solidified bars are known as "pigs," and are approximately 3 ft. long and 3 in. to 4 in. thick. Pig iron, after remelting and again being allowed to solidify in moulds, is called cast iron. The two terms, pig iron and cast iron, are often used synonymously, although there is actually a difference between the two, the cast iron being the more pure.

The iron content of the pig iron is usually from 90 to 95 per cent. Impurities present include carbon, sulphur, silicon, phosphorus, arsenic, and manganese. The most important of these elements is carbon, which may be present in pig iron to the extent of from 1·5 to 8 per cent. Cast iron usually contains not less than 3 to 4 per cent. carbon, and is usually present in the free state as graphite, or combined, as carbide of iron (Fe_3C), known as cementite. Most irons contain carbon partly in each state. Where most of the carbon is free, upon breaking the iron the fracture shows a dark-grey colour, and is called grey iron. When the carbon is all in combination, the fracture is a shiny silver white, showing no traces of graphite and is called white iron. Intermediate stages between these two show patches of grey in the white structure of the iron, and this variety is called "mottled."

The character of the metal is determined by the proportion of the two types of carbon, graphite and iron carbide, present within the iron. Graphite is tough and soft, and in pig or cast iron, where the graphitic constituent predominates, the iron is easily drilled or machined. Alternately, carbide of iron, or the combined carbon of the iron, is very hard and brittle, and where this condition predominates, these properties are imparted to the metal.

Generally, in the case of pig or cast iron, when the combined-carbon content does not exceed ·25 per cent., the metal is soft. From ·25 per cent. up to a combined-carbon content of ·5 per cent., the tensile strength of the iron increases to a peak. When the combined-carbon content is 1 per cent., the metal is very brittle, and the hardness such that it is not economical to machine castings from it.

Pig or cast iron, completely fluid, contains carbon in the combined state, free carbon in the graphitic form only being produced during the cooling of the metal. During slow cooling, large flakes of graphite are

formed, thus imparting softness to a slowly cooled cast iron. Iron carbide (combined carbon) is formed in the iron by very rapid cooling of the molten cast iron, and therefore the metal is hard.

The melting point of cast iron is found to decrease as the proportion of carbon is increased. A pure iron has a melting point of 1,505° C.; with a carbon content of 1·5 per cent., the melting point is decreased to about 1,400° C.; and a carbon content of 3·8 per cent. shows a decrease to about 1,150° C.

The impurities in the iron considerably influence its properties. Iron having a silicon content of up to 2 per cent. is softened, as the silicon keeps the carbon in the soft graphitic condition. On the other hand, manganese enables more of the iron to combine with carbon and to retain a maximum amount of carbon in the combined form. Therefore, manganese invariably hardens the iron. The presence of sulphur always tends to produce unsound castings, and a good-quality cast iron should never exceed ·2 per cent. of sulphur.

Phosphorus is present in iron in the form of iron phosphide (Fe_3P). Its effect is to increase the fluidity of the molten metal. For "fine" and ornamental castings, a phosphorus content up to 2 per cent. is allowable.

Grading of Pig Irons.—The usual grading of pig iron is by means of a series of numbers from 1 to 4, 5 or 6, followed by "mottled" or "white." The latter denotes irons lower in silicon and total carbon,

Stanton Irons

Grade	*Combined Carbon*	*Graphitic Carbon*	*Total Carbon*	*Silicon*	*Sulphur*	*Phosphorus*	*Manganese*
	%	%	%	%	%	%	%
Stanton Siliceous .	Trace	3·50	3·50	4/5	·016	1·35	·47
Stanton No. 1 Foundry	·15	3·50	3·65	3·50	·015	1·40	·45
Stanton No. 2 Foundry	·20	3·49	3·69	3·20	·020	1·44	·45
Stanton No. 3 Foundry	·30	3·35	3·65	2·91	·025	1·34	·46
Stanton No. 4 Foundry	·40	3·15	3·55	2·45	·050	1·40	·44
Stanton No. 4 Cylinder	·60	2·91	3·51	2·16	·064	1·38	·43
Stanton No. 4 Forge .	·80	2·52	3·32	1·95	·090	1·39	·39
Stanton Mottled .	1·50	1·60	3·10	1·25	·280	1·30	·33
Stanton White . .	2·90	Trace	2·90	·90	·350	1·30	·29

Goldendale Irons

Goldendale No. 1 .	·35	3·48	3·83	3·12	·025	·46	2·14
Goldendale No. 2 .	·46	3·24	3·70	2·76	·032	·47	2·04
Goldendale No. 3 .	·51	2·97	3·48	2·52	·041	·45	2·02
Goldendale No. 4 .	·59	2·72	3·31	2·07	·054	·43	1·93
Goldendale No. 5 .	·71	2·47	3·18	1·90	·062	·47	1·87
Goldendale No. 6 .	·83	2·16	2·99	1·36	·073	·46	1·54

and higher in sulphur and combined carbon as the number increases. Graphite is highest in number 1, diminishing until in white iron the whole of the carbon is in the combined state. As an example, the grading of the Stanton irons is shown in table on opposite page.

Goldendale irons are higher in manganese and much lower in phosphorus content, and tabulated from 1 to 6 (see table on opposite page).

The characteristics of the grades indicated in the table are roughly as follows :

No. 1.—Foundry quality is a soft grey iron, containing a high proportion of carbon and silicon. It is mechanically very weak and melts readily. Owing to its weakness, it is used mainly for thin castings where strength is unimportant.

No. 2.—Foundry quality is lighter in colour, having a closer crystalline fracture with less distinct graphite flakes. Compared with No. 1, it is harder and stronger, less fluid when molten, and used only for light castings.

No. 3.—Foundry and forge quality is less graphitic, more finely divided than No. 2, and has a smoother and closer fracture. It is harder than No. 2, stronger, denser, and less fluid when molten. It is largely used for foundry-work covering a wide range ; the forge quality is used for the manufacture of wrought iron.

No. 4.—Foundry and forge quality, still less fluid when molten and whiter than No. 3. The forge quality is harder and denser than the foundry quality. The latter is used for high-quality castings, such as steam cylinders.

Nos. 5 *and* 6 are still closer and harder, and suitable for forging purposes, or chilled castings.

Mottled iron comprises a matrix of white iron, having specks of grey iron scattered through it.

White iron is extremely hard, having a close-grained white fracture and containing little or no graphite. It is suitable for foundry purposes.

ALLOY CAST IRON.—During the last twenty years, considerable development has taken place in the alloying of various metals with cast iron. The latter was considered a hard metal, lacking in tensile and transverse strength, and especially in its ability to withstand shock loads.

The age-old trouble with machining cast iron is hard spots, chill, and porosity under the skin. By alloying with a low nickel content of ·5 to 1·5 per cent., these disadvantages give little or no trouble. The average nickel content is 1 to 1·5 per cent., with a silicon content of 1·25 per cent. and ·7 per cent. manganese to a base iron having 3·2 per cent. total carbon. These low nickel irons, although easily machinable, are fairly hard, and have a fine grain which will give a polish finish, and are fairly resistant to corrosion. They average approximately 18 tons per square inch in tensile with a Brinell Hardness Number of 210.

There are three main properties of cast iron which can be brought out

by suitable alloying: (1) Hardness, combined with machinability. (2) High tensile strength. (3) Resistance to corrosion and heat. Irons of the "Ni-Hard" group are associated with wear, the base iron being usually alloyed with 3 to 4·5 per cent. nickel, 1 per cent. chromium, ·7 per cent. silicon and ·8 per cent. manganese. Suitable composition will give a hardness up to 800 B.H.N., and strength of 50 per cent. above that of plain cast iron without loss of toughness. This iron can be given a surface hardness of 900 B.H.N. by the nitrogen process, and has a tensile strength of 25 to 30 tons per square inch.

In the second group are the irons falling in the "Ni-Tensyl" category, which average a tensile strength of 23 to 25 tons per square inch, with an average B.H.N. of 250. They are fine-grained, have a high shear strength combined with some elasticity, and have good machining qualities. The toughness of the material in this group can be simply improved by stress annealing at 400° C., and the tensile strength raised to 35 tons per square inch by oil quenching at 800° C. and tempering at 300° C.

The third group contains the irons falling in the "Ni-Resist" category. The total carbon content is retained at about 3 per cent., with a higher silicon content of 1·5 per cent. They are usually produced in the foundry by the addition of N.C.C. (nickel-chromium-copper) to the base iron. Copper is one of the elements assisting impartation of corrosion resistance to the iron, although its content is usually only about 2 per cent. This grade is a relatively soft material of about 180 B.H.N. and a tensile strength of about 16 tons per square inch. Apart from resistance to corrosion, "Ni-Resist" irons are heat resisting, and retain 50 per cent. strength at 700° C.

Wrought Iron

Wrought iron contains over 99 per cent. of pure iron, and is made from either the iron ore or cast iron, and produced at a temperature below its own melting point. It is produced by the puddling process, and is malleable, ductile, and fibrous in structure. It comes from the puddling furnace in a malleable mass, which is subsequently hammered and rolled, and always contains intermingled slag. It contains so little carbon that it will not usefully harden when rapidly cooled. The composition varies with the quality, and it is desirable to keep the phosphorus content below ·25 per cent., and sulphur below ·05 per cent. Good average wrought iron has an ultimate tensile stress of about 25 tons per square inch.

Malleable Iron

Malleable cast iron compared with ordinary cast iron is less brittle, stronger, and more ductile. Malleable castings can be hammered and bent, but not forged.

ALLOY CAST IRONS.

Description of Iron		Total Carbon	Silicon	Manganese	Nickel	Chromium	Tensile Strength Tons/□"	Brinell Hardness
NICKEL CAST IRON for light sections	for machinability, strength, density, and wearing quality.	3·3	1·8	·7	1·5	—	18	220
NICKEL CAST IRON for medium sections		3·2	1·2	·7	1·25	—	18	210
NICKEL CHROMIUM CAST IRON medium sections		3·2	1·6	·7	1·25	·5	18	220
NICKEL CHROMIUM CAST IRON heavy sections		3·2	1·0	·7	1·25	·5	18	200
NICKEL-CHROMIUM C.I.	for heat resistance.	3·2	1·2	·8	1·0	1·0	17	250
NI-TENSYL	for maximum strength.	2·9	1·5	·8	1·5	—	22	220
HARD GREY IRON	for maximum wearing quality and machinability without heat treatment.	3·3	1·2	·8	3·0	·5	20	300
MARTENSITIC IRON	for wearing quality where maximum hardness as cast is required.	3·3	1·2	·8	5·0	·75	20	400
HEAT-TREATABLE CAST IRON for light sections	for wearing quality and strength after heat treatment.	3·3	1·6	·7	2·0	—	25	350
HEAT-TREATABLE CAST IRON for heavy sections		3·2	1·4	·7	2·5	·5	25	300
NICKEL WHITE IRON	for improved toughness and hardness in white iron castings.	3·0	·7	·8	1·5	·5	22	450
NI-HARD	for high-hardness and toughness in white or chilled cast iron.	3·0	·7	·8	3·0	·75	22	550
	for maximum hardness and toughness in white or chilled cast iron.	3·0	·7	·8	4·5	1·5	22	650
NOMAG	for non-magnetic castings.	3·0	1·5	7·0	11·0	—	16	180
NI-RESIST	for resistance to corrosion and heat.	3·0	1·5	1·0	14·0	2·0	16	180
NICROSILAL	for maximum heat resistance.	1·7	4·5	·8	18·0	2·0	16	180
LOW-EXPANSION CAST IRON.		2·2	1·5	·8	34·0		14	180

The two processes of production are the Reaumur process and the Blackheart, or American, process. Both have white iron as a basis, and can be differentiated as follows :

(*a*) Reaumur process, in which the cast iron suffers a loss of carbon.

(*b*) Blackheart process, in which the combined carbon in the white iron is changed into annealing carbon.

The Reaumur process is the typical English process. The castings are fettled and packed in cast-iron pots along with an oxidising material, such as red hæmatite ore, mill scale, etc., and completely isolated from each other. The cast-iron lids are put on the pots, all air spaces being sealed with clay, and the pots placed in the annealing oven. They remain thus for two or three days, during which the temperature is slowly raised to 850° to 880° C., this temperature being maintained for a further three to four days, when a cooling period of about four days is allowed.

The Blackheart process is almost identical with the Reaumur process, the main difference being that the packing materials used are non-oxidising, such as sand, etc. Temperatures are lower, the average being 770° to 840° C. Blackheart castings are kept as free as possible from sulphur content, as this, if present in any considerable amount, plays a very destructive part. The manganese content, however, is usually higher than in the Reaumur process. The sulphur content in the British white irons usually renders them unsuitable for a basis of Blackheart malleable cast iron. The fracture shows a velvety black " heart " or core, surrounded by silky grey edges, and it is from this appearance that the name is derived.

The mechanical properties of the metal are compared below giving approximate figures.

White Cast Iron : 11 tons per square inch maximum stress.

Reaumur Malleable Cast Iron : 25 tons per square inch maximum stress, with 5 per cent. elongation on 2 in. and 6 per cent. reduction of area.

Blackheart Malleable Cast Iron : 20 tons per square inch maximum stress, with 10 per cent. elongation on 2 in. and 10 per cent. reduction of area.

British Admiralty Specification : 18 tons per square inch maximum stress, and 4·5 per cent. elongation on 2 in.

Steel

The two essential elements present in steel are iron and carbon. Other elements present are impurities which are not essential to the formation of steel. The chief of the latter are manganese, sulphur, phosphorus, and silicon.

Manganese is useful in steel as long as it has a neutralising effect on sulphur. If manganese is present in steel, the sulphur will combine with

this element in preference to iron, and form manganese sulphide. The latter, although not desirable, has no weakening effect upon the steel, as is the case with iron sulphide. To ensure that no iron sulphide is formed, it is usual to have about six times more manganese than sulphur present. When the silicon content is less than ·3 per cent., it is not injurious, but on the other hand improves the soundness by diminishing blow holes. Larger silicon content modifies the properties of the steel by entering into solid solution. Phosphorus content should be as small as possible, otherwise the metal will be brittle and the resistance to shock be lowered. If phosphorus is present in sufficient quantities, it is liable to combine with the iron and form phosphide of iron.

The definitions of steel vary, some relating to the carbon, or alloy content, and others to the manufacturing process. What is generally termed mild steel is a low carbon content steel of from ·05 to ·4 per cent. carbon. Steels up to ·2 per cent. carbon content will not harden by the usual heating to red and quenching, but can be case-hardened. Steels from ·2 to ·4 per cent. carbon content can be hardened to some extent by the usual heating to red and quenching in water. These mild steels are largely used in structural work, drop forgings, angle and channel, etc. Mild steel is often designated as Bessemer steel, and is produced practically direct from pig iron. In the Bessemer process, the molten pig is poured into the Bessemer converter, and a blast of air forced through it, which produces an intense heat. By this means the impurities are oxidised and burnt up, some passing off as gases and others are absorbed by the special firebrick and clay lining of the converter. In practice a manganiferous pig iron called "spiegeleisen" is put into the converter to help clear away the oxides formed.

The open-hearth or Siemens-Martin steel is said to correspond with Bessemer steels. In the open-hearth process, it is usual to make use of scrap steel, or scrap wrought iron, as the high temperatures obtainable by the regenerative furnace allow them to be brought to a molten state. The iron is melted in a reverberatory furnace and red hæmatite added to oxidise the carbon, silicon, and manganese. Carbon is then added in the form of spiegeleisen and ferro-manganese. The air and gas are passed through regenerative chambers before entering the combustion chamber, and are heated to about 1,200° F. If the scrap contains too much phosphorus, burnt lime is added to the charge in order to keep the slag basis, and steel made on this principle is called "basic."

In both the Bessemer and open-hearth processes, the steel is produced from the iron by the removal of the carbon.

Steels having a carbon content of ·4 to ·65 per cent. are classified as medium-carbon steels, and can be hardened and tempered.

Blister steel is produced by the cementation process, and is the most important preliminary process employed in the manufacture of crucible steel. Best selected bars of wrought iron are placed in a cementation

furnace, surrounded and packed in with charcoal. A temperature sufficient to keep the bars at blood-red heat is maintained for about nine days, the actual period being determined by the amount of carbon content required in the steel ; this usually ranges from ·6 to 1·6 per cent. Upon removal from the furnace the bars are found to be covered with blisters. Single-shear steel is produced by breaking the bars into short lengths, piled and reheated, treated with a flux of borax and sand, and welded together and drawn into bars. Double-shear steel is produced by breaking the single-shear bars into short lengths, selected for fracture, and then piled, reheated, welded, and drawn.

Steels having a carbon content of ·7 to 1·5 per cent. are often classified as high-carbon steels. They are harder and stronger than those previously mentioned, but are generally more brittle. Cast steel is a special range of carbon steels, having a carbon content of 1 to 1·5 per cent.

Crucible Steel.—Cast or tool steel is usually produced by cutting lengths of blister steel into short lengths and melting them in a fireclay crucible. The carbon is added in the form of ferro-manganese.

A further method of producing cast steel is by cutting short lengths of best Swedish bar iron and melting them in airtight crucibles, together with an addition of charcoal and oxide of manganese and other elements as required. The necessary carbon is taken up from the charcoal. Swedish bar iron is almost completely free from carbon, and an addition of Swedish white pig is sometimes employed to give the desired carbon to the charge.

A general classification of carbon steels is given as a guide.

Classification of Carbon Steels

Carbon Content	*Application*
%	
·1 to ·2	Case-hardening steels, mild steel bars, sheets, tubes, angles, bolts, nuts, and general engineering.
·2 to ·4	Medium carbon steels, machine spindles, gear shafts, torque tubes, bolts, nuts, pressings, forgings, etc.
·4 to ·5	Automobile steels, high-tensile steels, drop forgings, stampings and pressings, steel castings.
·5 to ·6	Stronger steel castings, tools for hot working.
·6 to ·7	Tools for hot work and dull edges.
·7 to ·8	Hammers, miners' tools, cold sets.
·8 to ·9	Drills, taps, reamers, cold sets, dies.
·9 to 1·0	Best all-round tool steel.
1·0 to 1·1	Large lathe tools, cutters and milling tools, hot sets, planing tools, small drills, dies, circular cutters, etc.
1·1 to 1·5	Lathe tools, planing tools, cutters, small drills, scribers, scrapers, etc.

Alloy Steels

Alloy steels are those containing one or more elements apart from iron

and carbon, and sufficient in quantity to modify and improve its physical properties.

The chief advantages of alloy steel over carbon steel are greater maximum strength in tension, compression and torsion, and increased hardness and toughness. High-speed steel gives harder and stronger cutting edges to machine tools, etc.

Nickel steels are the most numerous of the alloy steels, as the nickel content increases the strength without appreciably affecting the ductility of the steel. Nickel steels can be divided into two classes : (1) Low nickel-content steels, having ·2 to ·35 per cent. carbon and 3 to 5·5 per cent. nickel content. (2) High nickel steels have about the same content of carbon as before, but the nickel content is 25 per cent. or more. High nickel steels are non-magnetic, corrosion resisting, and have a very low coefficient of heat expansion. For these reasons the "Invar metal," containing 36 per cent. nickel, is used for making pendulums and rods for measuring instruments, etc.

Nickel-chromium steels, having a chromium content up to 1·5 per cent. and nickel up to 3·75 per cent., are most generally used. The carbon content is from ·15 to ·4 per cent., and in addition are small percentages of silicon and manganese. By the addition of the two main alloying elements, the steel is given hardness and strength from the chromium, together with ductility and toughness from the nickel.

Nickel-chrome steels are made in four grades—mild, medium, high tensile, and self-hardening—each successive grade stronger than the preceding one. In all grades special heat treatment is necessary. The uses of these grades can be classified : mild grade, where strength has to be combined with lightness, as for axles and machine parts ; medium grade, where highly stressed parts are subject to shock, as connecting rods, etc. ; high tensile grade, for certain highly stressed aircraft parts, cranks, and connecting rods of Diesel and petrol engines. The air-hardening nickel-chrome steel contains usually about 1·25 per cent. chromium. This steel is very strong, tough, and hard, giving a maximum tensile strength of 100 to 130 tons per square inch and a B.H.N. of 430 to 560.

Manganese steel contains about 1·25 per cent. carbon and 13 per cent. manganese. Although containing 86 per cent. magnetic iron, manganese steel is practically non-magnetic. It is very tough and most difficult to cut, and is rendered softer and tougher by quenching. When suitably heat treated, it has a tensile strength of from 60 to 73 tons per square inch, with an elongation of from 50 to 73 per cent., and a tenacity of 19 tons. Under deformation it has an inclination for hardness up to B.H.N. 600. Castings made from manganese steel are remarkably free from blow holes, and as when molten it is very fluid, intricate shapes can be readily cast. It can also be rolled into sheets and plates.

High-speed steels contain about 16 per cent. tungsten, 4 per cent. chromium, and ·6 per cent. carbon. This steel is hardened like carbon

steel, by rapid cooling from a high temperature. Hardness and cutting qualities are retained at a low red heat when heavy rapid cuts are being taken. To improve its qualities, it is now the practice to add about 1 per cent. vanadium.

Cobalt high-speed steels contain cobalt, in addition to vanadium, tungsten, chromium, molybdenum, and carbon, and are used for making high-speed cutting tools. The cobalt content is usually 2 to 5 per cent., and such steels will give very hard and tough cutting edges when suitably hardened. The B.H.N. is from 650 to 750, which is rather more than is the case in most other high-speed steels.

Non-ferrous Metals

So far consideration has been given to some of the most important ferrous metals, i.e. metals having an iron base. The further metals to be considered are non-ferrous, or having an extremely low iron content, and include copper and aluminium alloys.

Copper is probably the most important metal in use apart from iron, and when alloyed to other metals, gives a very extensive range of applications. Copper, next to silver, is the best electrical conductor of all metals. The tensile strength in the drawn rod, or annealed, form, is 13 to 14 tons per square inch, and in the hard-drawn, or wire, form of 18 to 30 tons per square inch. In the last case, the highest value corresponds to the smallest wires. Annealed copper wire has a tensile strength of 14 to 16 tons per square inch.

Copper Alloys

There are many copper alloys, of which the following are considerably used in the engineering industry: brasses, bronzes, gun-metals, etc. Strictly speaking, brasses come within the copper-zinc alloys and bronzes within the copper-tin alloys.

Ordinary cast brass has a copper content of 63 to 67 per cent. and zinc content of 30 to 35 per cent. Its tensile strength is 14 to 17 tons per square inch.

Cartridge brass has a copper content of 70 per cent. and zinc content of 30 per cent. The ultimate tensile strength is 19 tons per square inch. This brass possesses a high degree of ductility, and can be severely cold worked without becoming brittle. It is used for tube and cartridge cases.

Muntz metal has a copper content of 60 per cent., with 40 per cent. zinc content. The ultimate tensile strength is 22 tons per square inch, and it is used for castings, and hot-worked, rolled, extruded, or stamped products.

Naval brass has a copper content of 62 per cent., with 37 per cent. zinc and 1 per cent. tin content. The effect of the tin is to increase the strength and hardness, but to reduce the ductility. The ultimate tensile strength is 26 tons per square inch.

Phosphor-bronze has a copper content of 90 per cent., with 9·7 per cent. tin and ·3 per cent. phosphorus. The average tensile strength is 17 tons per square inch. This bronze can be cast into various shapes, and is obtainable in the form of drawn bars and rods of various sections.

Manganese bronze has an average copper content of 56·6 per cent., zinc 39·9 per cent., tin 1 per cent., iron 1·4 per cent., manganese ·8 per cent., and aluminium ·25 per cent. It has an average tensile strength of 28 tons per square inch, and is used for pump rods, nuts, and propeller blades. The corrosion-resisting properties are exceptionally good.

Gun-metal has a copper content of 85 to 92 per cent. and the remainder tin. Soft gun-metals contain 90 to 92 per cent. copper, whilst the harder grades contain from 85 to 87 per cent. copper. Lead and nickel are frequently added, and the alloys are particularly resistive to corrosion, and used for bearings, steam-pipe fittings, etc.

Admiralty gun-metal has a copper content of 88 per cent., zinc 2 per cent., and tin 10 per cent. The ultimate tensile strength is 14 tons per square inch, and it is used for hydraulic valves and marine machinery.

Aluminium and Aluminium Alloys

Aluminium is a light ductile metal with high electrical conductivity and good resistance to corrosion. When exposed to air, it takes on a fine film of oxide, which can be improved by the anodic treatment. It is fairly ductile and malleable, especially over 100° C., but at 530° C. it is so brittle that it can be powdered. Aluminium ignited at high temperatures burns brilliantly and attains an extremely high temperature. It is upon this fact that the principle of "Thermit" welding has been evolved. It will dissolve in many acids and in a solution of potash and caustic soda. It is obtainable in hard, half-hard, and softer conditions, and in sheets of 98 to 99·8 per cent. pure aluminium. In the rolled condition the tensile strength is about 12 tons per square inch, and in cast conditions of about 5 tons per square inch.

Duralumin is an aluminium alloy, and is probably the most important and most widely used. The approximate composition is: copper 4 per cent., magnesium ·6 per cent., manganese ·6 per cent., iron ·3 per cent., and the remainder aluminium. The tensile strength can be improved from 18 to 26 tons per square inch by normalising. In the annealed state the B.H.N. is approximately 60, and when normalised 90 to 115.

Aldural has the characteristics of duralumin, but possesses greater corrosion resistance. Aldural can only be produced in the form of rolled metal, consisting of a coating of pure aluminium of about 5 per cent. the thickness of the core, on each side of rolled duralumin. It has a strength slightly less than duralumin, but as good a degree of ductility.

Alclad is another sheet metal having both sides coated with pure aluminium over a duralumin core. These coated metals are very much

used for flying-boat hulls and other positions exposed to sea air or water conditions.

Aldal has an average composition of copper 4 per cent., magnesium ·5 per cent., manganese ·5 per cent., silicon ·6 per cent., and the remainder aluminium. It is hard, and has a tensile strength of 25 to 35 tons per square inch.

"Y" alloy is similar to duralumin, with the addition of nickel and magnesium. The average composition is: copper 4 per cent., nickel 2 per cent., magnesium 1·5 per cent., silicon ·3 per cent., iron ·3 per cent., and the remainder aluminium. After normalising and ageing for five days, it has a maximum ultimate tensile strength of about 22 tons per square inch. It has a cleaner structure than duralumin and less liability to corrode.

Elektron

The principal constituent is magnesium, which is about twice as strong as aluminium, weight for weight. The composition varies as follows: aluminium 3 to 12 per cent., manganese ·2 to ·4 per cent., and sometimes zinc ·5 to 3·5 per cent., with a magnesium base. Elektron alloys are available in a wide range of forms, including castings, sheet, rod, strip, extrusions, etc., and according to their form, give tensile strengths from 6 to 26 tons per square inch and B.H.N.s from 40 to 100.

Alpax is an aluminium-silicon alloy containing 87 per cent. aluminium and 13 per cent. silicon. It is ductile, fine-grained, and a silvery-white colour. The tensile strength is 10 to 12 tons per square inch, elongation 5 to 8 per cent., and B.H.N. of 60. It has good casting qualities and corrosion resistance. It is also known as Silumin.

Monel Metal is a nickel-base alloy containing nickel 68 per cent., copper 29 per cent., and manganese, carbon, iron, silicon, 3 per cent. The tensile strength is about 33 tons per square inch, with about 45 per cent. elongation. It has good corrosion-resisting properties, and is used for propellers, pump fittings, condenser tubes, etc.

Consideration has been given to some of the most commonly used metals and alloys. Those desirous of pursuing the subject further are referred to the D.T.D. and British Standard Specifications and other authoritative sources.

Chapter XIV

ENGINEERING HARDENING PROCESSES

Heat Treatment

THE purpose of heat treatment is to improve the physical properties of the metal, and so impart to it the essential qualities required for a particular job. Heat treatment may also be necessary to restore the metal to its normal condition after being worked at high temperatures.

To be successful, heat treatment must be carried out strictly in accordance with the material manufacturer's or other authoritative specifications. It is the inspector's responsibility to ensure that these conditions are complied with, and to make the necessary tests after treatment.

Alloy steels have critical points, i.e. definite temperatures at which, in both heating and cooling, certain changes take place in the chemical composition of the steel. At normal temperatures, the carbon content in steel is present in the form known as " pearlite " ; this form is changed to " martensite " or hardening carbon, when the steel is heated to a certain temperature. If the steel is allowed to cool slowly, the structure reverts to its normal condition, i.e. pearlite. The decalescence and recalescence, or otherwise known as critical points, are the points at which these changes occur. The decalescence point can be defined as that point at which steel, being heated, although continuing to absorb heat, does not show any appreciable rise in temperature. The recalescence point, on the other hand, is the point during cooling from a high heat at which there will be an increase of temperature, although the surrounding air may be colder. The recalescence point is lower than the decalescence point by anywhere between 85° F. and 215° F. Unless the steel is uniformly heated up to a temperature sufficient to reach the decalescence point, i.e. the point at which the pearlite is changed to hardening carbon, no hardening action can take place. Also, unless the steel is cooled suddenly before reaching the recalescence point, i.e. the point at which the hardening carbon changes to pearlite, again no hardening can take place.

If the steel is heated beyond its decalescence point it will become non-magnetic, and it is upon this fact that certain methods of determining the decalescence point have been evolved. The different steels have their varying critical points which are specified according to the material, and must be adhered to. The carbon content in the steel determines the temperature and degree of hardness ; the higher the carbon content, the lower is the hardening temperature.

Method of Heating

Metals undergoing heat treatment require to be heated in a suitable furnace. Where the process is regularly carried out, a pyrometer is essential to maintain the required temperature. The usual type is the thermo-electric ; the thermo-couple is housed in the muffle, and the action of the heat on it creates a current of air which is recorded on a meter calibrated in degrees Fahrenheit. Sentinel cones can be used where the amount of hardening to be done does not warrant the expense of the more reliable instruments. The cones are placed in the hardening chamber, and being numbered according to the temperature at which they melt, will therefore melt at that particular temperature for which they are selected, thus indicating the temperature in the interior of the furnace.

The method of judging the temperature by colours is to be discouraged as unreliable, although skilled men can estimate to a fair degree of accuracy by this means.

Quenching

The steel to be hardened should be heated slightly in excess of the correct hardening temperature to allow for temperature drop during transfer to the quenching tank. Generally, cooling should be performed at a constant rate and as rapidly as possible. The type of steel will determine the nature of the coolant, which may be either water, oil, oil and water, brine or air.

Most tool steels are oil hardening, but high-carbon steel will harden in water. In the latter case, when the formation of the tool is such that hardening cracks may be formed, it is usual to cover the top of the water with a film of oil.

Clean water, at a temperature of not less than 60°, should be used for water hardening. Soft water, or water containing a proportion of washing soda, is preferable to hard water. In the case of oil hardening, the oil should be thin and have a high flash point. Special oils are available.

Hardening Baths

In this process, the components to be hardened are immersed in a bath of molten lead or metallic salts. The solution is maintained at the required hardening temperature, and is suitable for small and intricate parts, such as taps, dies, etc. Uniformity of heating is assured, as no part of the components can reach a temperature varying from that of the bath. One of the salts most extensively used is barium chloride.

Tempering

After hardening, tool steel is very brittle, and needs to be toughened

before it can be expected to give efficient service. Tempering is simply taking away some of the brittleness by the application of heat. For small quantities of tools, the heated sand-bath method is employed. The hardened end of the tools is polished bright and the tools placed in the bath, shank end first, with the cutting edge showing so that the temper colours can be observed. The sand being heated from below, the heat will travel from the shank end to the cutting edge. It is observed that a definite series of oxide film colours (temper colours) travel along towards the cutting edge and, varying from the straws to the blues, serve as a rough guide to the temperature. A list of tempering colours is given below. When the temper colour, approximating to the desired temperature, almost reaches the end of the tool, the whole is quenched in either water or oil.

TEMPER COLOURS AND APPROXIMATE TEMPERATURES

Colour	° C.	° F.	*Suitable for Tempering*
Very light straw	220	430	Scrapers, etc.
Light straw	226	440	Turning tools, etc.
Pale straw	232	450	Hammer faces, light lathe tools, etc.
Straw	237	460	Steel and iron planers, etc.
Dark straw	243	470	Drills, milling cutters, etc.
Dark yellow	248	480	Reamers, boring cutters, etc.
Yellow-brown	255	490	Chasers, penknives, etc.
Brown-yellow	260	500	Punches and dies, plane irons, etc.
Spotted-red-brown	265	510	Wood-boring tools, etc.
Brown-purple	270	520	Twist drills, augers, etc.
Light purple	277	530	Press tools, axes, hot sets, etc.
Full purple	282	540	Cold chisels and sets, etc.
Dark purple	288	550	Cold chisels for cast iron, cutters for softwood, etc.
Full blue	294	560	Screwdrivers, circular saws for metal.
Dark blue	300	570	Springs, wood saws, etc.

Tempering in Oil

For large quantities of tools the oil bath is often used. Tools to be hardened must be placed in the bath when the oil is cold; this applies for each batch to be treated. Owing to the danger of fire should the oil become too hot, it is necessary to carefully select an oil having a high flash point. Heavy black oil will give a flash point of 725° F., and when using this oil, the maximum temperatures required for tempering must be well below this figure.

Pyrometric control of temperature is now favoured in all bath-tempering processes, the tools being removed for quenching when the pyrometer records the required degree of heat.

Annealing

Annealing is a heat treatment in which it is desired to obtain one or all of the following aims :

(*a*) To restore the perfectly crystalline structure of the metal, which may have been interfered with by previous cold working.

(*b*) To soften the metal for easy machining.

(*c*) To refine the grain of the metal, giving increased ductility.

(*d*) To relieve the internal strains which may have been set up due to rapid cooling in previous heat treatment.

Pieces of steel can be annealed by placing them in boxes, packing with sand, lime, or fireclay, and excluding the air. The boxes are heated in a muffle furnace to the point just above decalescence, and without removing them from the furnace, allowing them to cool slowly.

Annealing is extended to non-ferrous metals as well as ferrous metals, the underlying principle being the same, but for different metals the temperatures, cooling period, and conditions vary.

Normalising

The purpose of normalising a steel is to refine its grain structure and relieve any stresses, and to present it in the most suitable form for machining or heat treatment. Normalising is often confused with annealing, and it is essential that the differences in the processes should be clearly understood. Normalising can be defined as heating a steel, however previously treated, to a temperature exceeding its upper critical point, and allowing it to cool in air. (Except in the case of hypereutectoid steel, i.e. a steel containing more carbon than is contained in pearlite. In carbon steels a hypereutectoid steel is one containing more than ·9 per cent. carbon, and in this case is only heated to just above the lower critical point.) The temperature should be maintained for about 15 mins., depending upon the shape of the part, and not exceed the upper critical point by more than 50° C. The difference between normalised and annealed steel is that normalised steel usually has a finer grain and the pearlite is not lamella, i.e. having a structure resembling a thin plate, as in annealed steel, but fine and almost structureless. The latter is called sorbitic pearlite, or fine pearlite, and is harder and stronger than lamellar pearlite. Normalising increases the yield point and the tensile stress, but maintains the ductility.

Case-hardening

Case-hardening, as the name implies, is a process whereby a steel is given a hard surface, which will withstand abrasion and at the same time retain a tough core.

Low carbon-content steels are generally used for parts which require to be case-hardened. The B.S.I. specifies ·2 per cent. carbon as the

maximum allowable. Steels having a carbon content of ·1 to ·2 per cent. will not harden, but will satisfactorily respond to the case-hardening process. It is the high carbon-content in tool steels which enables them to be hardened by heat treatment, and to enable mild steel to be case-hardened carbon must be introduced into the surface of the metal, thereby giving it a high carbon-content. This is the first operation in case-hardening, and is called case carburising. This is performed by heating a low carbon steel, such as mild steel, above the upper critical point, whilst being in contact with a mixture of carbonaceous materials. The latter may be either of the patent compounds which are available, or some form of animal charcoal, such as ground bone, charred leather, or cuttings from horses' hoofs, etc. The steel is heated, together with the compound, in a sealed iron box or fireclay crucible. The carburising mixture forms carbon monoxide, which penetrates into the case of the steel, and the depth to which it penetrates is as a rule not exceeding $\frac{1}{16}$ in., depending upon the period of heating.

Owing to its slow cooling, the carburised steel will not have a sufficiently hard surface, and in addition, owing to the time which it has been heated above the upper critical point, will have a coarse-grained case. To rectify these deficiencies, the steel is heated to above the upper critical point of the core and quenched. This operation will refine the core, and the final operation, which will harden and refine the case without affecting the core, is to heat the steel to just above the lower critical point and quench.

Nickel Case-hardening Steels

Nickel present in steel has of itself a hardening effect, and where this condition exists, lower carbon contents are allowable. The B.S.I. Specifications for nickel case-hardening steels are :

		Per cent.
Carbon content .	not exceeding	·16
Silicon content .	not exceeding	·30
Manganese content .	between ·20% and	·60
Sulphur content .	not exceeding	·05
Phosphorus content .	not exceeding	·05
Chromium content .	not exceeding	·30
Nickel content .	2·5 to 3·5% for 3% nickel steel.	
	4·5 to 6·0% for 5% nickel steel.	

Cyanide Hardening

Cyanide hardening is a further case-hardening process, and consists of soaking small components in a steel pot containing sodium cyanide, or molten potassium. The working temperature of the bath is about 870° C., and after soaking for about half an hour the parts are quenched

in water. This method gives an economical and effective surface hardness to steels.

Another cyaniding process is the activated sodium cyaniding bath, which is used, in addition to case-hardening, for annealing, re-heating, and for the heat treatment of medium- and high-carbon steels. The bath is activated by the addition of calcium cyanide, and the temperature ranges from 730° to 900° C., being determined by the conditions requiring to be fulfilled. A case depth of $\frac{1}{32}$ in. can be obtained after three hours, and the components quenched in water or oil, depending upon the composition and purpose of the components.

Nitriding

Nitriding is a comparatively recent process, introduced to give a very hard surface at low temperatures and without the necessity for quenching. The advantages are :

(1) The extremely hard case obtained.

(2) Prevention of distortion by the low temperature at which the process is carried out.

(3) Owing to the temperature being less than the lower critical point, previous heat treatment is not affected.

(4) High corrosion resistance.

For this process special steels are used, which are known as nitralloys, having a chromium content of about 1·5 per cent. and aluminium 1 per cent.

The depth of casing depends upon the time allowed under treatment, and about $\frac{1}{32}$ in. can be obtained in ninety-five hours.

The process consists of placing the components in a sealed box, through which ammonia gas is circulated, and heating up to 500° C. in a furnace.

Ordinary chromium steels can be treated by this process by first copper-plating the parts to be treated.

Nitriding slightly increases the dimensions of the components and leaves a brittle outer skin. This only amounts to about $\frac{2}{1000}$ in., which is removed by buffing.

Chapter XV

MECHANICAL TESTING OF MATERIALS

WHEN designing machinery, the designer has to predetermine the dimensions of all parts of the machine according to their particular functions. To be able to calculate the necessary sizes, he must know the various types of load, tension, compression, shear, torsion, or bending to which the parts are to be subjected. Again, after ascertaining the type of load, he must decide the most suitable material to be used for each part and, from accumulated data regarding the strength of the material, he can calculate his dimensions. The accumulated data is obtained by mechanical testing of various materials, and it is the task of the inspector to make these tests and to see that all materials for special purposes fulfil the requirements of the material specification. The Air Ministry issues D.T.D. Specifications covering all types of aircraft materials, and the B.S.I. has compiled many specifications regarding the most suitable tests for a very large range of materials.

Mechanical Properties of Materials

Apart from strength and elasticity, there are several other mechanical properties which must be considered in determining the suitability of a certain material for a specific purpose. They can be defined as :

(1) DUCTILITY.—The property giving the ability to withstand a large degree of deformation without fracture, i.e. to take on a permanent extension under tensile test without breaking.

(2) MALLEABILITY.—The property which allows a material to be permanently deformed without fracture when rolled or beaten. It is very similar to ductility.

(3) TOUGHNESS.—The ability to resist fracture when subjected to a sudden blow, bending, or twist.

(4) BRITTLENESS.—The lack of ductility, toughness, or malleability.

(5) HARDNESS.—The resistance to wear. The property of a material to resist scratching or denting by another material.

Load

The term load usually expresses the total external forces acting on any section of a piece of material, and is expressed in either pounds or tons.

Stress

In all cases where the material is under load, internal forces are set up to resist this load (or external forces), and are termed stresses. The intensity of the stress is calculated as the force acting on unit area of cross section, and expressed in either pounds or tons per square inch, the square inch being taken as the unit area.

Thus :
$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

Types of Load

TENSION.—When a load acts on a rod, as shown in Fig. 177, tension is produced, and the load is called a "tensile load." If the diameter of the rod is known, the tensile stress, written f_t, can easily be calculated.

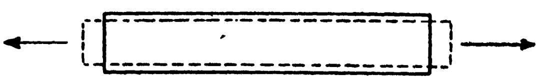


Fig. 177.—TENSION

Example.—A steel rod 1 in. diameter is pulled with a force of 2 tons. Find the tensile stress produced in the rod.

$$\text{Tensile stress, } f_t = \frac{\text{Load}}{\text{Area}} = \frac{2}{\cdot 7854 \times 1^2} = 2{\cdot}547 \text{ tons per square inch.}$$

COMPRESSION.—When a load acts on a rod as shown in Fig. 178, compression is produced, and the load is called a "compressive load." The diameter of the rod being known, the compressive stress, f_c, can be calculated.

Example.—A steel bar of 1¼ in. square section carries a compressive load of 10 tons. Calculate the compressive stress produced in the bar.

$$\text{Compressive stress, } f_c = \frac{\text{Load}}{\text{Area}} = \frac{10}{1{\cdot}563} = 6{\cdot}40 \text{ tons per square inch}$$

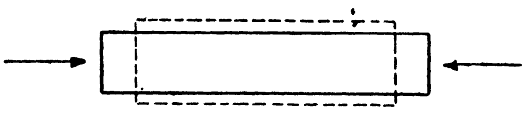
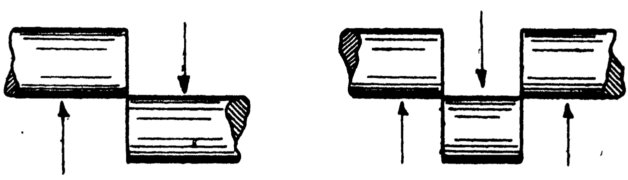


Fig. 178.—COMPRESSION

SHEAR.—When loads act as shown in Fig. 179, they are called shear, and produce shear stresses, f_s. Many examples of shear stress are encountered in engineering practice, such as bolts, rivets, bearing pins, keys, etc.



SINGLE SHEAR DOUBLE SHEAR

Fig. 179.—SINGLE AND DOUBLE SHEAR

Example 1 (*Single Shear*).—Two pieces of steel are bolted as shown in Fig. 180. If the joint is subjected to a direct pull of $1\frac{1}{2}$ tons, calculate the shear stress in the bolt. Size of bolt $= \frac{3}{4}$ in. diameter.

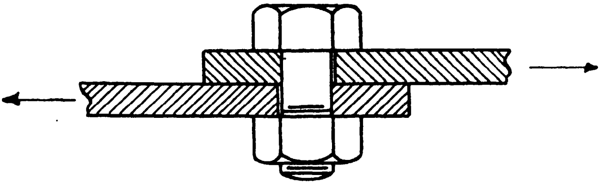


Fig. 180.—EXAMPLE OF SINGLE SHEAR

$$\text{Shear stress, } f_s = \frac{\text{Load}}{\text{Area}} = \frac{1\cdot5}{\cdot4418} = 3\cdot39 \text{ tons per square inch.}$$

Example 2 (*Double Shear*).—A knuckle joint is shown in Fig. 181. Find the shear stress in the pin, the joint being subjected to a direct pull of 4 tons, and the pin 1 in. diameter.

$$\text{Shear stress, } f_s = \frac{\text{Load}}{\text{Area}} = \frac{4}{2 \times \cdot7854 \times 1^2} = \frac{4}{1\cdot5708}$$
$$= 2\cdot546 \text{ tons per square inch.}$$

TORSION.—A load which produces a twisting action is called a torsional load. The result of this load is a shear stress of an amount which varies from zero at the centre of the part under load to a maximum at the greatest radius.

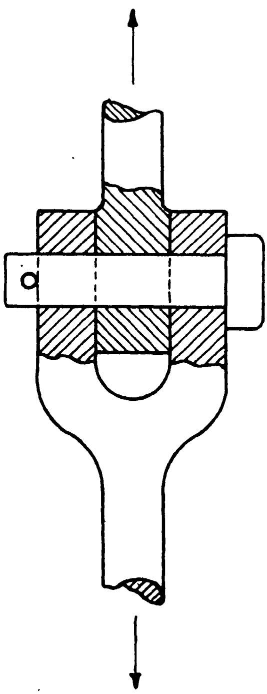


Fig. 181.—KNUCKLE JOINT-EXAMPLE OF DOUBLE SHEAR

BENDING.—An applied load can cause bending, which produces a combination of stresses, tension, compression, and shear.

Strain

Strain can be defined as a measure of the deformation caused by the application of external forces. The strain value is simply the ratio of the deformation to the original form, and as such is merely a number having no unit.

Tensile strain is given by :

$$\text{Tensile strain} = \frac{\text{Increase in length}}{\text{Original length}}$$

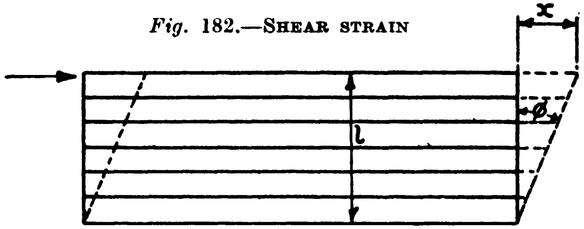
In the same way, compressive strain is given by:

$$\text{Compressive strain} = \frac{\text{Decrease in length}}{\text{Original length}}$$

For shear strain refer to Fig. 182, the ratio being :

$$\text{Shear strain} = \frac{x}{l} = \tan \phi$$

Fig. 182.—SHEAR STRAIN



Elasticity

The elasticity of a material is the property which allows the material to return to its original shape after the strain set up by the load has been released. This property of elasticity is of great importance, as all materials used in engineering design are stressed within the elastic range.

Hooke's Law

Hooke's law states that within the limits of elasticity stress is proportional to strain, and from this the ratio is obtained :

$$\frac{\text{Stress}}{\text{Strain}} = \text{Constant}$$

As strain is merely a number, the unit for the constant will be the same as for the stress, either lb./sq. in. or tons/sq. in. This ratio is called the modulus of elasticity, or Young's modulus, and is often represented by the letter E. If a rod is stressed to 10 tons/sq. in. and has a strain value of ·002, then from Hooke's law :

$$\frac{\text{Stress}}{\text{Strain}} = \frac{10 \text{ tons/sq. in.}}{\cdot 002} = 5{,}000 \text{ tons/sq. in.} = \text{Modulus of elasticity } (E)$$

It must be remembered that the value of the modulus can only be applied within the limits of elasticity, and this value is practically constant for any particular material. If the modulus of elasticity is known, the extension, or elastic stretch produced by a given load in any material, can be calculated.

Example.—A steel rod ½ in. diameter × 5 ft. long carries a tensile load of 2,000 lb. Calculate the tensile stress and the total elongation produced. $E = 30{,}000{,}000$ lb./sq. in.

$$\text{Tensile stress } (f_t) = \frac{2{,}000}{\cdot 7854 \times \cdot 5^2} = \frac{2{,}000}{\cdot 1964} = 10{,}183 \text{ lb./sq. in.}$$

$$\text{Modulus } (E) = 30{,}000{,}000 = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Strain} = \frac{10{,}183}{30{,}000{,}000} = \cdot 00034$$

$$\text{Total elongation} = 5 \times 12 \times \cdot 00034 = \cdot 0204 \text{ in.}$$

Elastic Limit

The B.S.I. has summed up the definition of elastic limit as follows : " The elastic limit is the point at which the extensions cease to be pro-

portional to the loads. In a stress-strain diagram plotted to a large scale, it is the point where the diagram ceases to be a straight line and becomes curved."

Limit of Proportionality

The limit of proportionality is the point at which the intensity of stress ceases to be proportional to the strain. Both the elastic limit and the limit of proportionality are for many materials the same, but owing to the difficulty in obtaining the latter, it is rarely used in commercial specifications. The elastic limit also is impossible to determine by ordinary commercial testing, very sensitive instruments being required. These are considered later.

Yield Point

The yield point is the point at which the extension shows an increase under tensile load, without a corresponding increase in the load. The corresponding stress is called the yield stress. This point is clearly marked in the case of wrought iron and low carbon-content steels, and for this reason is often specified instead of the elastic limit. In the case of non-ferrous metals and alloy steels, the yield point is not so clearly defined and proof stress is usually specified.

Ultimate Stress or Strength

The ultimate stress is calculated from the maximum load obtained during test, divided by the original cross-sectional area. To obtain the working stress, the ultimate stress is divided by a number called the factor of safety. The ultimate stress is always specified for tests, and is the measure of tenacity.

Actual Stress

The actual stress is taken at the point where the waist is formed during the test and where the actual fracture will take place. The value is calculated from :

$$\frac{\text{Load at fracture}}{\text{Cross-sectional area at waist}}$$

This value is not used in commercial testing.

Nominal Stresses

In calculating the various stresses from the results of a tensile test, the original cross-sectional area is taken and the stresses called nominal stresses, since the actual cross-sectional area does not remain constant.

Percentage Elongation and Percentage Reduction of Area

The percentage elongation is based on the gauge length (the latter is explained under Forms of Tensile Test Pieces). Up to the maximum load the elongation is distributed practically uniformly over the test bar; after this point has been reached, local yielding occurs and the area of the cross-section decreases at the point of yielding.

The percentage elongation of a test piece, after fracture, is obtained from the equation:

$$\text{Percentage elongation} = \frac{\text{Gauge length after fracture} - \text{Original gauge length}}{\text{Original gauge length}} \times 100$$

The percentage reduction of area is expressed as:

$$\frac{\text{Reduction in area}}{\text{Original area}} \times 100$$

Both values are recorded to estimate the ductility of the material, but the percentage elongation is the most common. Materials having little or no ductility give so small an amount of elongation that no decrease occurs in the cross-sectional area and the test piece will break at the maximum load. In this case, the maximum stress will have the same value as the breaking stress.

General and Local Extension

After a test piece reaches the maximum load, it will neck and finally fracture. The length of the extension from the commencement of loading up to the maximum load is called the general extension. The further extended length, from this point up to fracture, which includes the neck or waist, is larger than elsewhere, and is called the local extension. The addition of general and local extensions gives the total extension.

Forms of Tensile Test Pieces

The proportions for cylindrical tensile test pieces are based on observations made by J. Barba, in which he found that geometrically similar test pieces deform similarly under tension. From this, if the ratio of gauge length to the diameter is constant, the percentage elongation is also constant. The gauge length is the parallel part of the test piece over which the extensions are measured. The accepted constant in British practice is:

$$4\sqrt{\text{Cross-sectional area of test piece}}$$

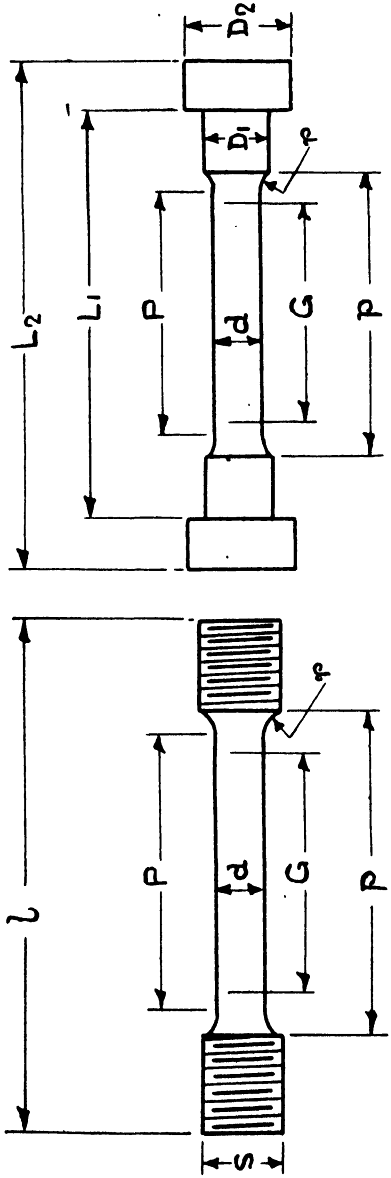
The standard test piece for general use is ·564 in. diameter, with a gauge length of 2 in. This can be checked from the previous constant as:

$$4\sqrt{\text{Area}} = 4\sqrt{\cdot 25} = 2 \text{ in.; or}$$

$$\text{Gauge length} = 4 \times \frac{\sqrt{\text{Area}}}{4} = 3{\cdot}55d;$$

Therefore, $3{\cdot}55 \times \cdot 564 = 2$ in.

Should the gripping arrangements for any testing machine require the test piece to be lengthened, this should be accomplished by adding the necessary amount to the machined ends and not by increasing the parallel length. Should the latter be lengthened, liability to fracture



The radius 'ρ' should be as large as is consistent with the other dimensions.

d	G	P	p	l	S	L1	L2	D1	D2
0·977	3·50	4·00	5	8	1·5 B.S.W.	6·25	8	1·25	1·75
0·798	3·00	3·375	4	6·5	1·25 B.S.W.	5·25	6·5	1·0	1·5
0·564	2·00	2·25	3	4·5	0·75 B.S.F.	4·25	5·25	0·75	1·25
0·358	1·25	1·50	2	3	0·50 B.S.W.	—	—	—	—
0·125	0·443	0·625	$\frac{7}{8}$	1·5	"O" B.A	—	—	—	—

Dimensions given in inches.

'G' = GAUGE LENGTH. d = DIA. OF TEST BAR. P = PARALLEL LENGTH OF TEST BAR.

Fig. 183.—British standard cylindrical test pieces

outside the gauge length is caused and consequent loss in percentage elongation.

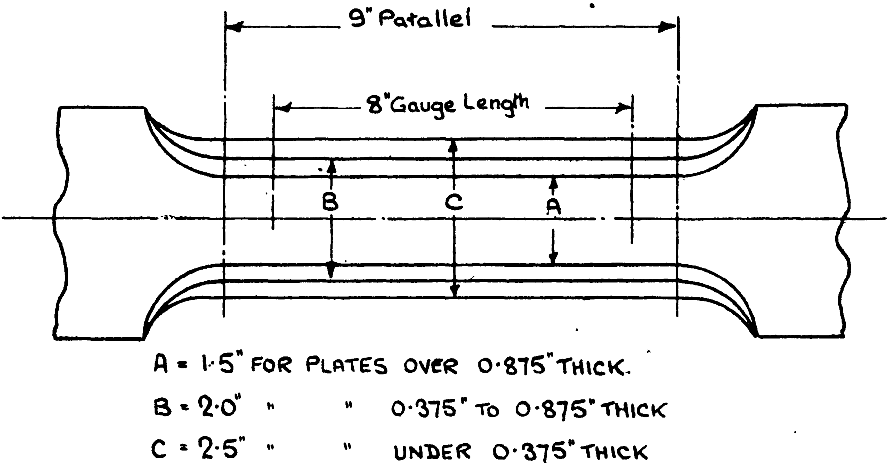


Fig. 184.—British standard plate test pieces

The British standard cylindrical test pieces are shown in Fig. 183 and the plate test pieces in Fig. 184.

Load-extension or Stress-strain Diagrams

The behaviour of a tensile test piece for a ductile material under ordinary commercial test can be conveniently plotted on a graph. The loads are plotted as ordinates and the extensions as abscissæ (Fig. 186).

Before commencing the test, it is necessary to mark off both the gauge length and "middle half" on the parallel portion of the test piece (Fig. 185). The fracture should occur near the centre of the gauge length to give the full percentage elongation value, and the local extension be within the gauge points. Providing the

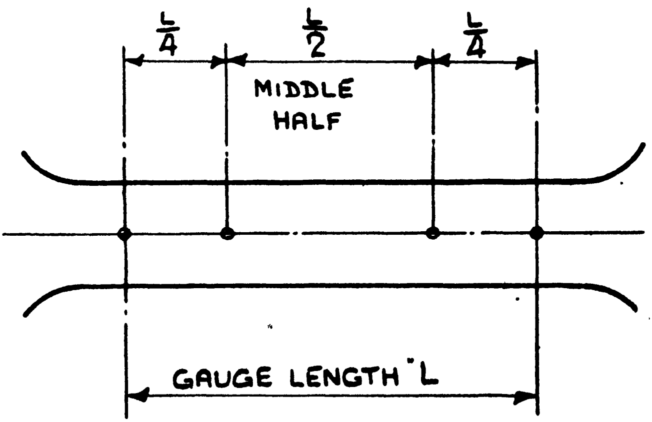


Fig. 185.—Proportions for "middle half"

fracture occurs within the " middle half," the test is usually accepted as satisfactory. On the other hand, should the fracture occur outside the " middle half," the specifications often provide that another test may be made. The proportions for the " middle half " are shown in Fig. 185.

Referring to Fig. 186, from zero up to the limit of proportionality, the load steadily increases, and the graph is a straight line, the load being proportional to the extensions or the stress proportional to the strain. The difference between elastic limit and the limit of proportionality has previously been explained.

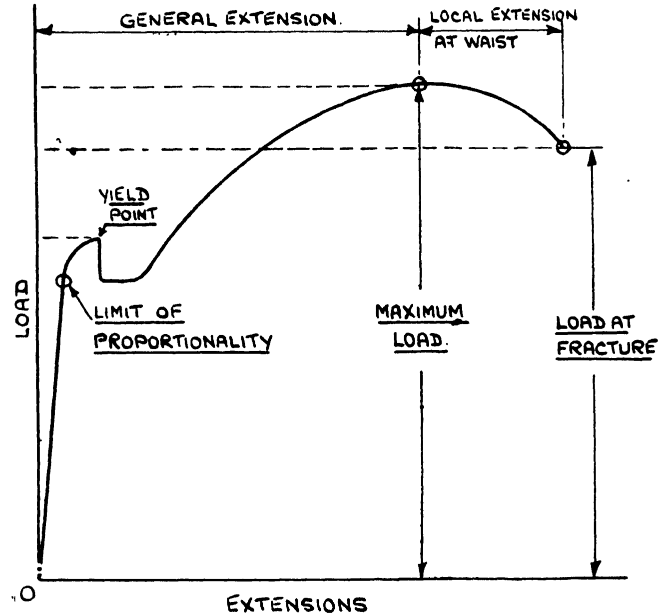


Fig. 186.—LOAD-EXTENSION DIAGRAM

Upon increase of load to the yield point, or yield load, the load suddenly drops (this is observed on the lever testing machine, by a drop of the lever). From this point the extensions increase without alteration of the load. Continuing the test, the load increases with an increase of the extensions until the maximum load is reached (this corresponds with the ultimate stress in a stress-strain diagram). Up to this point the reduction in area is comparatively small and the extensions general along the length. After this point the extensions increase with a decreasing load until the test piece breaks.

The diagram shown in Fig. 186 could be converted to a stress-strain diagram by taking the various loads and dividing them by the cross-sectional area of the test piece to obtain the stress, and dividing the extensions by the gauge length for the strain. The new values obtained would give an exactly similar graph. In the case of a test piece of gauge length 2 in., the procedure would be to multiply the load scale by 4 (the sectional area of the test piece being ·25 sq. in.) and dividing the extensions by 2. Fig. 187 shows a cylindrical test piece before and during test.

Proof Stress

Where, as in the case of non-ferrous metals and alloy steels, the yield point is not clearly defined, the proof stress is applied.

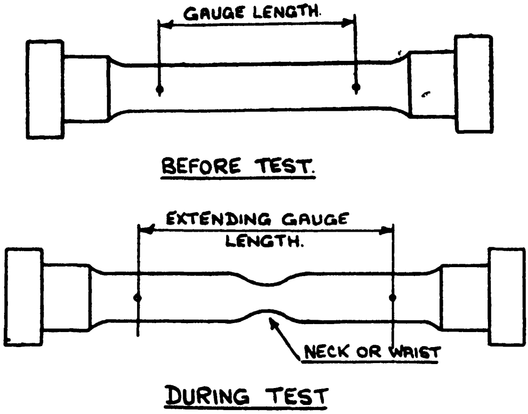


Fig. 187.—CYLINDRICAL TEST PIECE BEFORE AND DURING TEST

The B.S. Specification for ·1 per cent. proof stress is defined as "the maximum load per square inch which, when applied to a tensile test piece for 15 seconds and removed, produces a permanent extension of not more than ·1 per cent. of the gauge length." The percentages generally employed are ·1 per cent., ·2 per cent., and ·5 per cent. Further consideration is given to proof stress in Chapter XVII.

TESTING MACHINES

Avery-Buckton Universal Vertical Single-lever Testing Machine, No. 1015 (Fig. 188)

The type of machine illustrated has been designed to carry out tests in tension, compression, transverse, shear, torsion, and hardness. The capacities range from 5 to 100 tons.

If D.C. supply is available, the standard machines can be supplied with a 4 to 1 variable-speed motor, operating at 350/1,400 r.p.m., and giving crosshead speeds of $\frac{1}{4}$ in. to 1 in. per min. (the 5-ton machine has crosshead speeds of $\frac{1}{8}$ in. to $\frac{1}{2}$ in. per min.). The motor is geared to a worm drive, which operates a rotating nut (except on the 5-ton machine, which has a rotating screw), in which the straining screw moves up or down. The straining crosshead, which travels on machined guides on the column of the machine (*A*, Fig. 189), is connected by steel rods to a lower crosshead to which the straining screw is secured. The straining screw is fitted with a handwheel for making quick adjustments of the straining crosshead. A large handwheel is provided for making tests by hand power. The maximum load which can be applied by hand is approximately 5 tons.

Where A.C. supply is installed, it is standard practice to use a constant-speed A.C. motor to permit a straining speed of $\frac{1}{4}$ in. per min. Addi-

tional straining speeds can be provided by using a two or three fixed-speed A.C. motor. Back gearing can be used with a constant-speed motor permitting a straining speed of ¼ in. per min. and a setting speed of 1 in. per min.

Fig. 188 shows the standard arrangement of the weighing mechanism. The steelyard is scientifically balanced and fitted with knife-edges of selected hardened steel. The fulcrum knife-edge rests upon a hardened

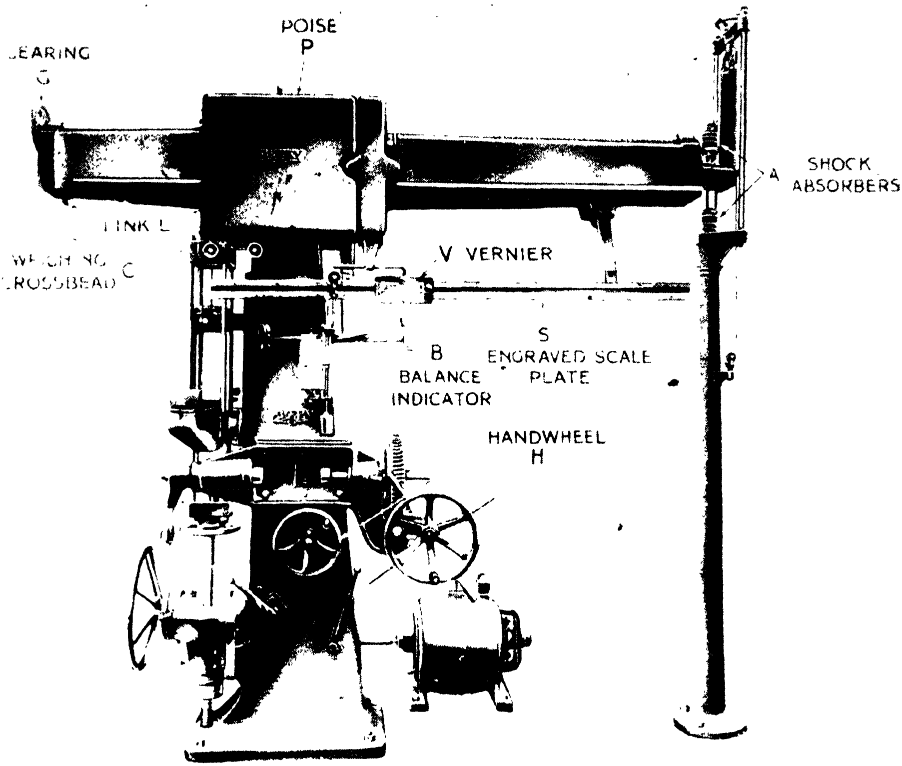


Fig. 188.—AVERY-BUCKTON UNIVERSAL VERTICAL SINGLE-LEVER TESTING MACHINE
(*By courtesy of W. & T. Avery, Ltd.*)

steel bearing arranged on the standard of the testing machine. The crosshead *C* is suspended from the load knife-edge of the steelyard by means of the link *L*. The standard machine has a single poise, *P* only, but this may be in two parts, as illustrated. When this is so, the proportion of the combined poise to the small poise is generally in the ratio of 5 to 1 for machines up to 25 tons capacity, but can be arranged at 10 to 1 for certain machines over that capacity. The load on the test piece is indicated upon a machine-engraved scale plate *S* by a vernier *V*

attached to the poise. When a split poise is used, the scale is provided with two independent sets of markings, one set graduated to the full capacity of the machine for use with the combined poise weight and one

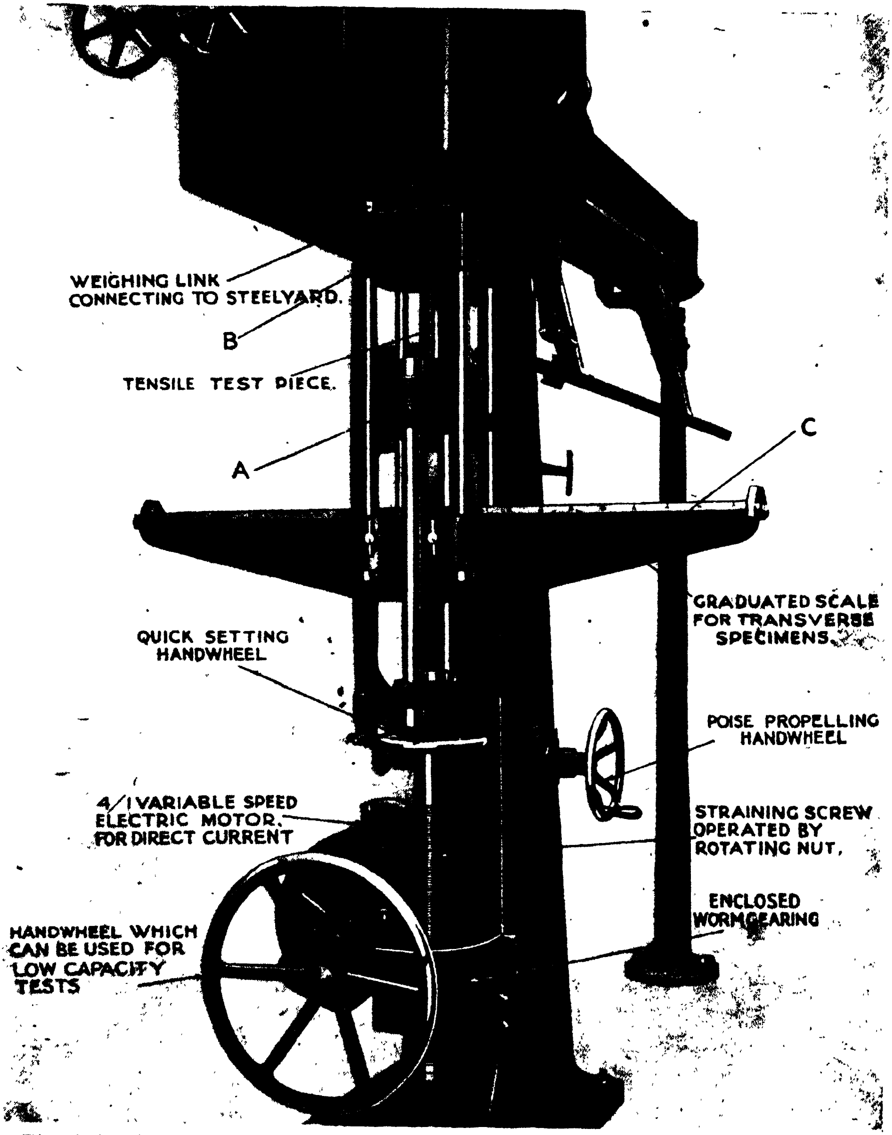


Fig. 189.—End view of universal vertical single lever testing machine
(*By courtesy of W. & T. Avery, Ltd.*)

set for use with the small poise, which allows fine graduations in proportion to the capacity; a third set of markings graduated in lb./in. can be provided if the machine is required for torsion testing.

The poise is mounted upon rollers having ball bearings, and is easily moved along the steelyard by means of the handwheel *H*, through bevel and spur gearing arranged at the back of the machine. The lay shaft is divided at the fulcrum knife-edge, and is provided with a universal joint to allow free flotation of the steelyard. A balance indicator *B* is arranged in a convenient position to enable the operator to keep the movement of the steelyard under observation. The shock absorbers *A*, at the end of the steelyard, prevent damage when the test piece breaks.

The end view of the machine is shown in Fig. 189. In any other test than torsion, the load is applied to the test piece by the downward movement of the straining crosshead *A*, the load being transmitted through the test piece to the weighing steelyard, where it is balanced off by the poise and indicated on the graduated scale.

METHOD OF MAKING TESTS.—The tensile test piece is positioned between the weighingcrosshead *B* and the straining crosshead *A* (Figs. 189 and 190). The compression specimen is placed on the beam *C*, which is suspended from the weighing crosshead by means of four steel rods. The load on the specimen, produced by the downward movement of the straining crosshead, is thus transmitted direct to the steelyard, where it is balanced off and indicated as in the tensile test. Fig. 191 shows a spring under compression test. The spring *A* is placed on a flat plate *B*, which rests on the bending beam, the latter being in connection with the steelyard and is compressed by the straining crosshead on its downward stroke.

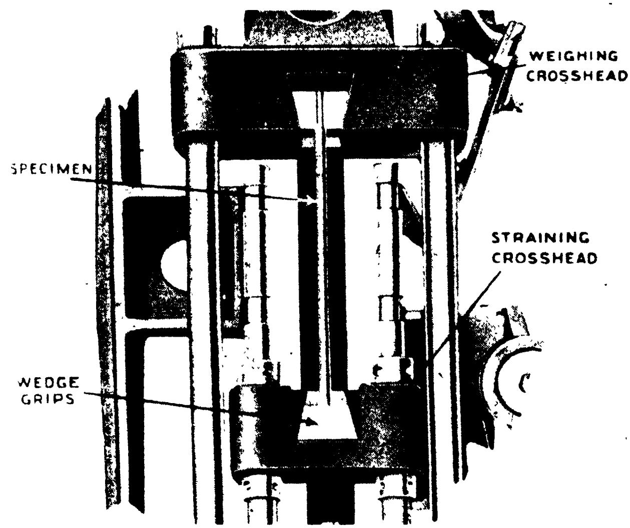


Fig. 190.—TENSION TEST
(*By courtesy of W. & T. Avery, Ltd.*)

Transverse tests can be made by supporting the transverse specimen on brackets on the beam *C*, and applying a load to the middle of its span

by means of a presser foot attached to the underside of the straining crosshead. A typical set-up is shown in Fig. 192.

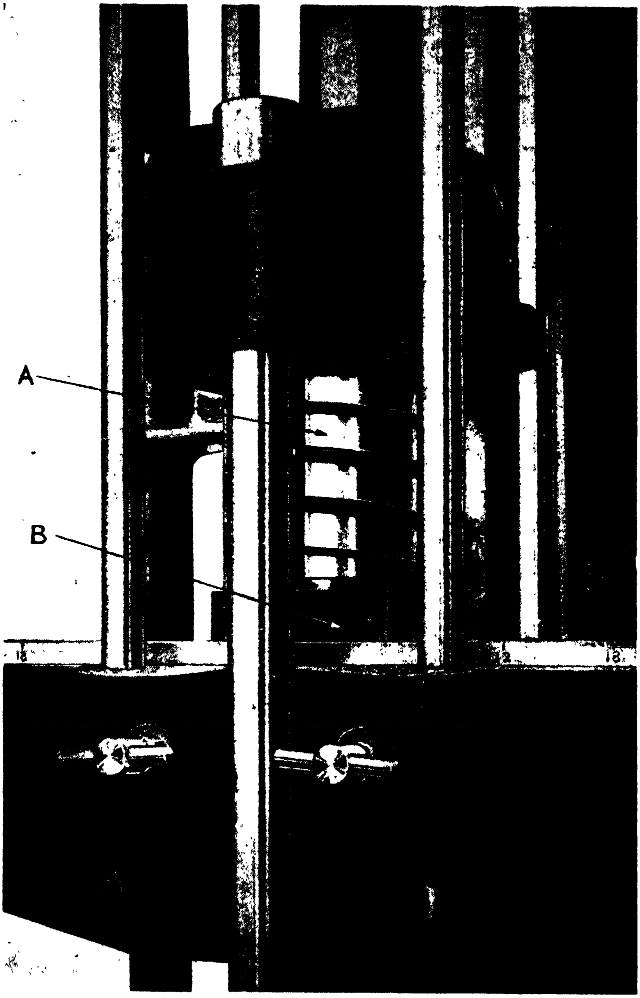


Fig. 191.—COMPRESSION TEST
(*By courtesy of W. & T. Avery, Ltd.*)

The double shear test is made between the compression platens. The shearing tools are used in conjunction with the compression tools, being designed to make double shear tests on round specimens. The specimen is passed through the hardened-steel bushes fitted in the lower bracket and top tool and positioned there (Fig. 193). The complete attachment is placed on the bending beam. The load is applied by the downward movement of the straining crosshead pressing on the top tool. The specimen is sheared across two sections, and the load is recorded on the graduated scale plate as in other tests.

Torsion tests are carried out by a special unit bolted to the column of the machine (Fig. 194). The specimen is held at one end in a holder *A*, which is attached to a shaft rotated by the handwheel *B*, through spur and worm gearing. At the other end the specimen is secured in the holder *C* mounted in ball bearings and attached to an arm, the end of which is in connection with a subsidiary knife-edge in the steelyard when torsion

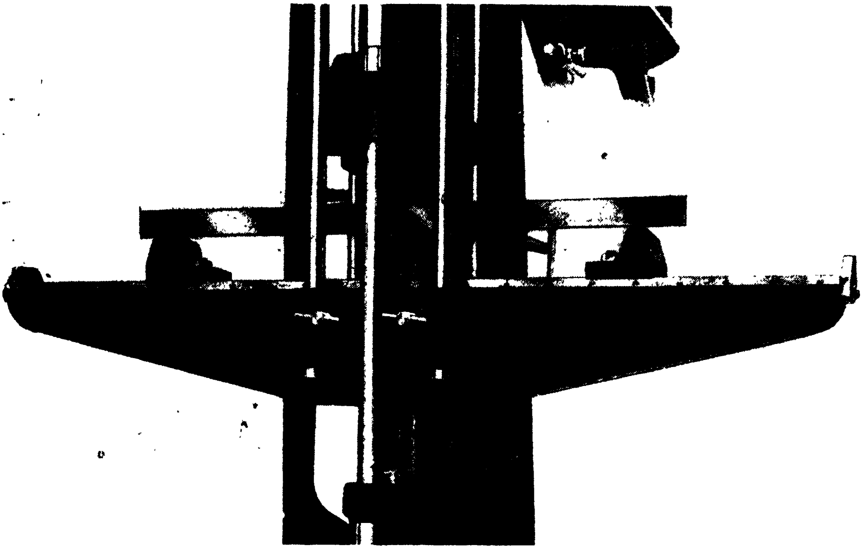


Fig. 192.—TRANSVERSE TEST
(*By courtesy of W. & T. Avery, Ltd.*)

tools are in use. The pull on the end of this arm, due to the movement of the poise weight on the steelyard, provides the necessary resistance to the torque applied to the specimen at A, and this is recorded in in./lb. on the steelyard scale. The specimen is prepared as shown in Fig. 195, and keyed to the adapters, which in turn are keyed to the holders, in the worm-shaft and lever end respectively.

The Brinell hardness test can be carried out by means of a special attachment fitted to the machine as shown in Fig. 196. Brinell hardness testing is considered in Chapter XVI.

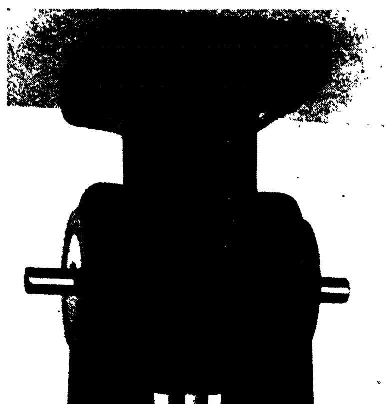


Fig. 193.—DOUBLE SHEAR TEST
(*By courtesy of W. & T. Avery, Ltd.*)

Autographic Recorders

Autographic recorders are used for automatically plotting the load-extension diagram of the complete test by the machine itself. There are two main types, the spring-loaded type and the geared type.

SPRING-LOADED TYPE.—This

recorder is of the drum type, and is mounted on a bracket attached to the main standard of the machine. It is arranged so that the vertical

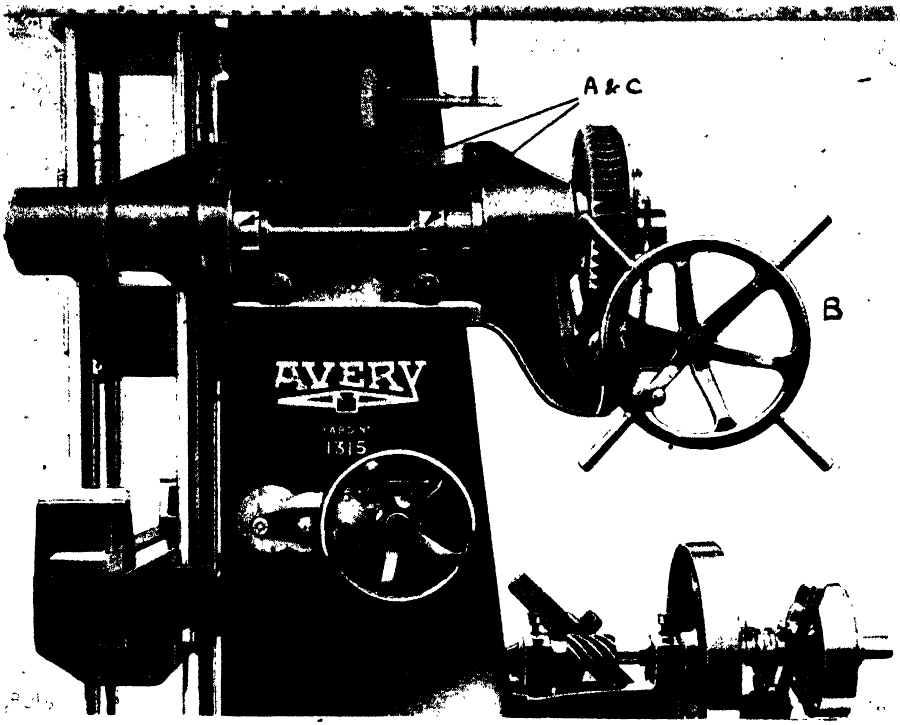


Fig. 194.—TORSION TEST
(*By courtesy of W. & T. Avery, Ltd.*)

ordinate on the graph represents the load and the horizontal ordinate indicates the extensions of the test piece. The recording pencil is moved in a vertical direction on guide rods by means of a steel tape passing

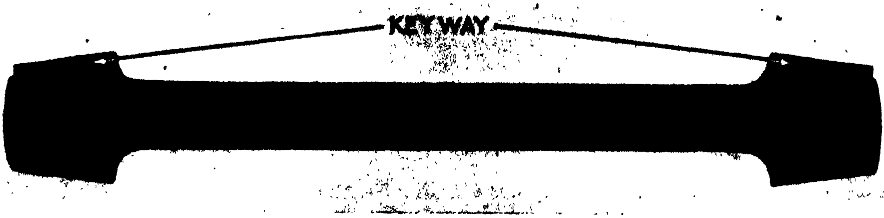


Fig. 195.—TORSION SPECIMEN
(*By courtesy of W. & T. Avery, Ltd.*)

round pulleys and in connection with calibrated springs at the end of the steelyard. The drum carrying the chart is revolved by a tape passing round suitably arranged pulleys and in connection with the top and bottom tension holders (Fig. 197).

GEARED TYPE.—This is also of the drum type and attached to the bracket carrying the poise propelling handwheel. It is arranged so that the horizontal ordinate on the graph represents the extensions and the vertical ordinate the loads. The recording pencil is traversed along the drum through spur and screw gearing by the poise propelling handwheel, whilst the drum is revolved by a cord passing round suitably arranged pulleys and attached to the straining holder (Fig. 198).

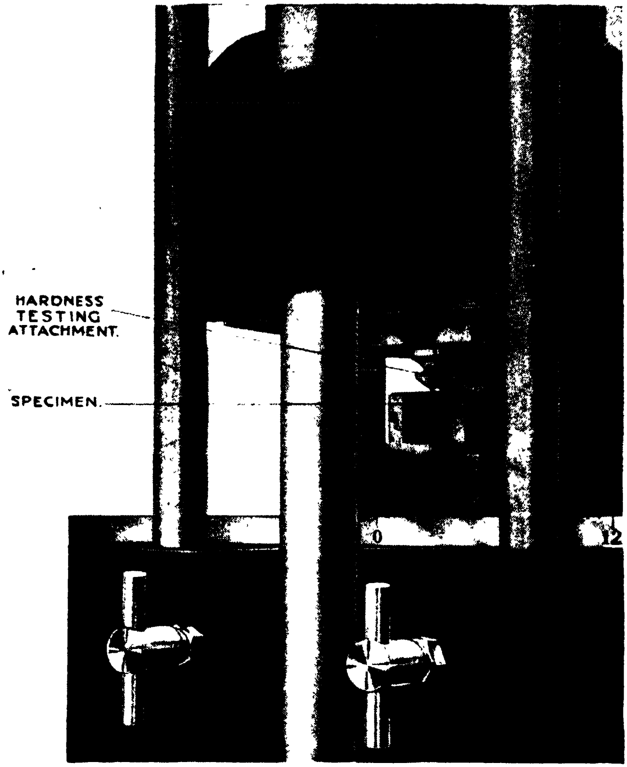


Fig. 196.—HARDNESS TEST
(*By courtesy of W. & T. Avery, Ltd.*)

Avery Compound-lever Type Universal Testing Machine, No. 708 (Fig. 199).

The principal advantage of this type of machine is its compact arrangement. The standard range covers capacities from 10 to 60 tons.

The table *A* rests on knife-edges fitted to cast-steel weighing levers in connection with a load-indicating steelyard *B*. The knife-edges and bearings throughout are of carefully hardened steel. The upper tension crosshead *C* is supported on steel columns secured to the compression table *A*. The straining crosshead *D* is secured to steel screws which engage with rotating nuts in the base box of the machine. The nuts are rotated by means of worm gearing and an electric motor *E*, the drive being transmitted through a gearbox *F*. A friction clutch *G* is provided

so that the crosshead speed may be controlled without frequent reference to the motor.

The machines can be used for tension, compression, transverse and shearing tests. The load is transmitted to table *A* in all cases, and thence via the weighing levers to the steelyard *B*, where it is balanced off and indicated by the poise. Effective recoil gear is provided to absorb shock on fracture of the specimen. When a specimen fails, the poise remains in position on the steelyard, and indicates, upon a machine - engraved scale secured to the steelyard, the load at which the specimen failed; a micrometer dial at the end of the steelyard subdivides the steelyard graduations. The micrometer dial is secured to the poise-propelling screw, and makes one revolution as the poise advances the pitch of the poise-propelling screw, thus permitting very fine increments of load to be indicated. An autographic recorder *J* can be supplied to give load-strain diagrams.

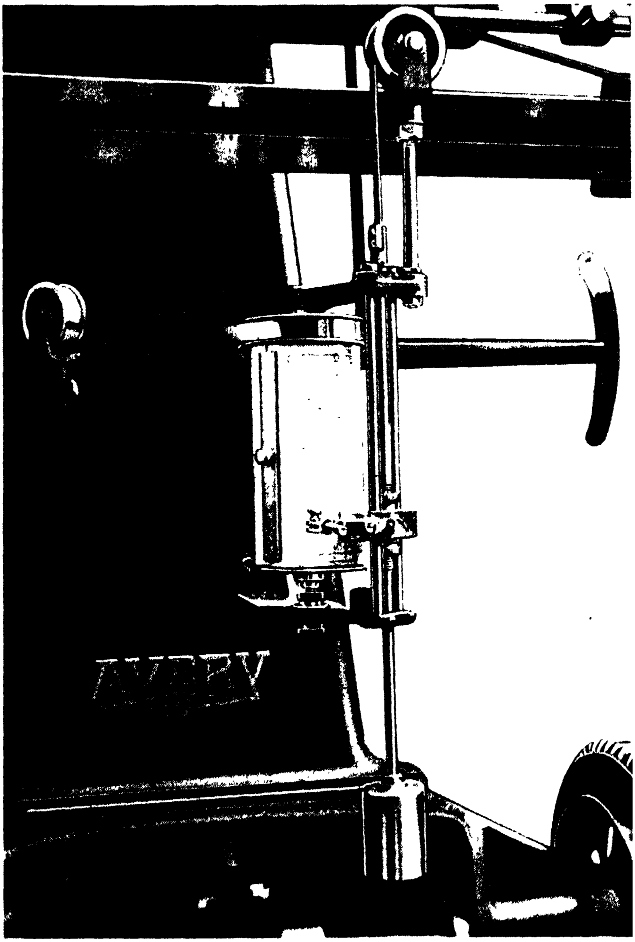


Fig. 197.—AUTOGRAPHIC RECORDER, SPRING-LOADED TYPE

(*By courtesy of W. & T. Avery, Ltd.*)

Avery Self-indicating Universal Testing Machine, No. A806/1474 (Fig. 200)

The machine comprises a dial indicator and a straining unit of single-

cylinder construction arranged so that the operator can remain seated throughout the test, with all controls readily to hand. Hydraulic loading, hydraulic transmission, and a heavy pendulum load resistant provide the basis of the design. The machine automatically cuts off at the moment of fracture.

An enlarged view of the dial indicator is shown in Fig. 201. Four ranges of capacity are provided on the chart. A machine of 10 tons capacity has a chart range of 10 tons, 5 tons, 2 tons, and 1 ton. This ratio is retained in the 30-and 50-ton machines. Graduations are widely spaced for clear reading. The same heavy pendulum is in operation for all charts, providing the same power factor for the minor as for the major range. The maximum pointer is reset by means of the knurled knob in the centre of the dial. Overloading is prevented by means of a release valve in the hydraulic supply, operated by the pendulum and operating on all charts. The indicator is zeroised by means of a knob at the right-hand side of the cabinet.

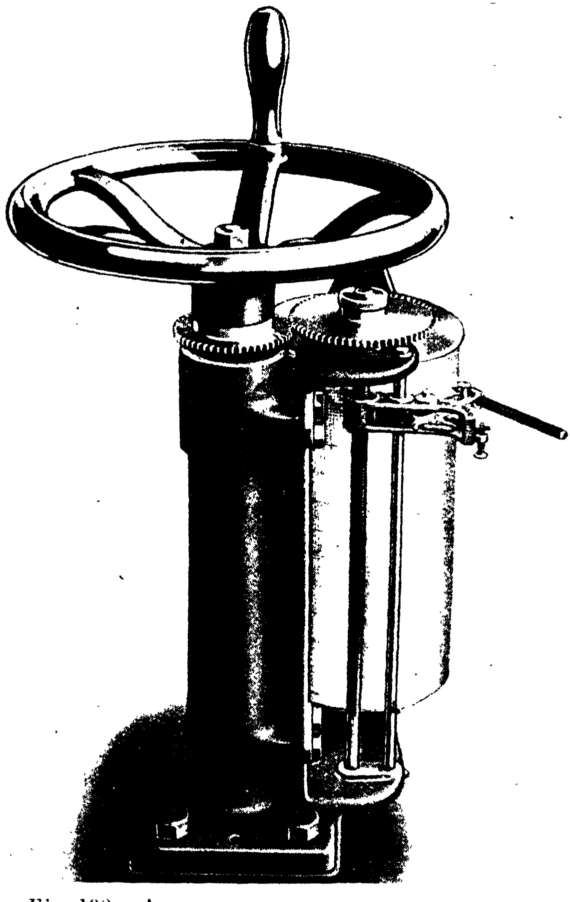


Fig. 198.—AUTOGRAPHIC RECORDER, GEARED TYPE
(*By courtesy of W. & T. Avery, Ltd.*)

By means of various attachments, the machine can be used for tensile, compression, shear, and transverse tests.

The Lindley Extensometer (Fig. 202)

The extensometer indicates alterations in length of ·00001 in. and accurately measures extensions to $\pm$·00005 in. The dial gauge is graduated in $\frac{1}{1000}$ in., and by a single lever the extension to the material under test

is magnified in the ratio of 2 : 1. One division movement of the pointer indicates an alteration in the length of the specimen of $\frac{1}{20000}$ in. The extensometer can be used on widths or diameters of $\frac{1}{4}$ in., $\frac{1}{2}$ in., ·564 in., and $\frac{3}{4}$ in. With suitable attachments it can be used on wire of ·015 in. to ·300 in. diameter.

Referring to Fig. 202, the extensometer consists of a body A with a rigid arm B. A similar arm C is hinged to the upper end of the column.

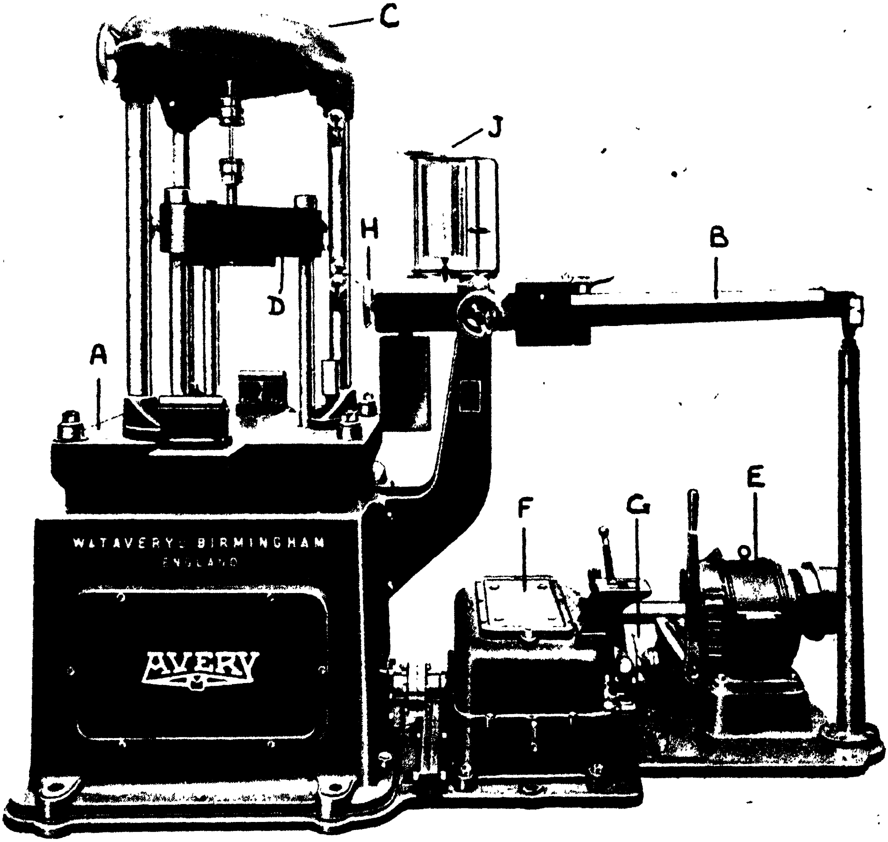


Fig. 199.—AVERY UNIVERSAL TESTING MACHINE, NO. 708
(*By courtesy of W. & T. Avery, Ltd.*)

A wide strip of spring steel forms the hinge and allows the arm to move in a vertical plane, whilst preventing sideways or rotational movement. During the test, the specimen is gripped between the ends of the screws E. The latter are operated by means of the thumbscrews F, through gears housed in casing G, and in such a manner that the vertical axis of

the specimen, whatever its thickness, is always coincident with the central plane of the extensometer. A spring-steel lever H is attached to the upper extensometer arm, passing down the front of the body and carrying a cone-shaped button. Pressure on the lever forces the cone into a hole at the base of the column, so arranged that when this is done the distance between the gripping screws is 2 in.

A hardened-steel bush is provided at the outer end of each arm and recessed to take the ball ends of the dial gauge, which are retained in position by means of forked springs. The extensometer is capable of a maximum extension of ·1 in. on the specimen, ·2 in. on the dial scale. The extensometer should be removed as soon as the test is completed. Fig. 203 shows the "Lindley" extensometer in position on a strip specimen.

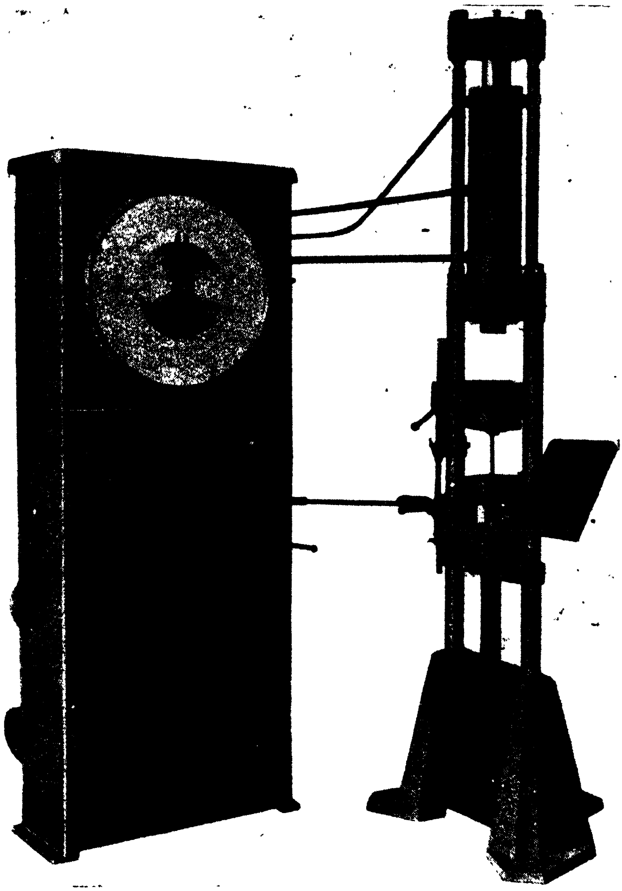


Fig. 200.—AVERY SELF-INDICATING UNIVERSAL TESTING MACHINE
(*By courtesy of W. & T. Avery, Ltd.*)

FATIGUE TESTS

The fatigue of metals plays a most important part in the designing of modern machinery. Experiments show that if stresses are repeated many times, the metal will fracture at a much lower stress value than the ultimate stress as found by the static test. If these repeated stresses are reversed, i.e. from tension to compression, the fracture will occur at a still lower stress value, and it is from this behaviour of metals, when subjected to fluctuating stress, that what is known as "fatigue of metals" is derived.

Wohler, and many experimenters since, have carried out considerable research work in connection with this subject, but the cause of failure has so far not yet been definitely ascertained, although several theories having much in common have been advanced.

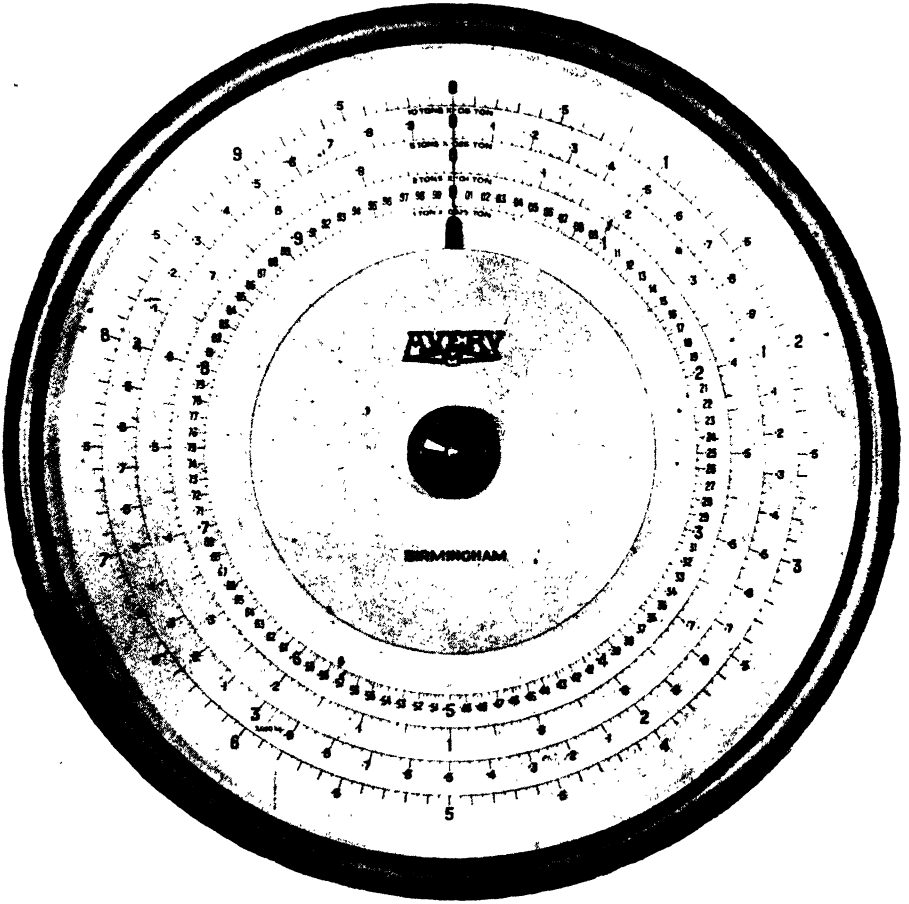


Fig. 201.—VIEW OF DIAL INDICATOR
(*By courtesy of W. & T. Avery, Ltd.*)

If the stresses fluctuate between a maximum and minimum value, and are of the same kind, they are said to be *varying stresses.* Should they fluctuate from opposite directions, i.e. from tension to compression, they are called *alternating stresses*, and if these stresses have the same value in both directions, i.e. 5 tons tensile 5 tons compressive, they are then known as *reversed stresses.* The *range of stress* can be defined as the alge-

braical difference between the maximum and minimum stresses thus: $R = f_{max.} - f_{min.}$. The *fatigue range* is the highest range of stress giving infinite reversals without failure. The number of fluctuations necessary to produce failure is known as *endurance*, and the *endurance limit* is the maximum stress giving infinite reversals without failure.

Types of Test Pieces used in the Wohler Test (Fig. 204)

There are two types of test pieces, the hollow and the solid type. The latter are now usually employed for all tests. The diameter varies,

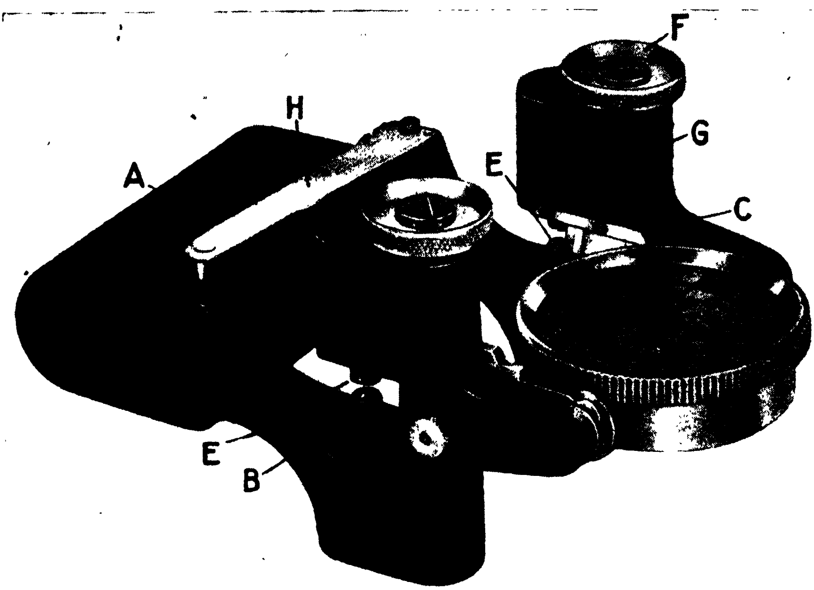


Fig. 202.—THE LINDLEY EXTENSOMETER
(*By courtesy of J. E. Baty & Co.*)

·400 in. for the weaker non-ferrous alloys down to ·25 in. for hardened-steel test pieces.

Avery Fatigue Testing Machine (Wohler System) (Fig. 205)

The fatigue range is most commonly determined by means of the Wohler reversed bending test, and this is carried out on a fatigue testing machine.

The test piece is carried in a split collet attached to the electric motor shaft and is a cantilever, the top half being in compression and the lower half in tension. The test piece is loaded by moving the jockey weight

along the steelyard until the load on the test piece is such that the maximum stress at the point as shown in Fig. 204 is :

$f_{max.} = \frac{32\ W\ L}{\pi d^3}$ Where W = Load applied

L = Leverage (3 in., see Fig. 204)

d = Diameter of portion of test piece under test (·25 in. to ·400 in.)

The electric motor usually runs at about 2,000 r.p.m., and the test

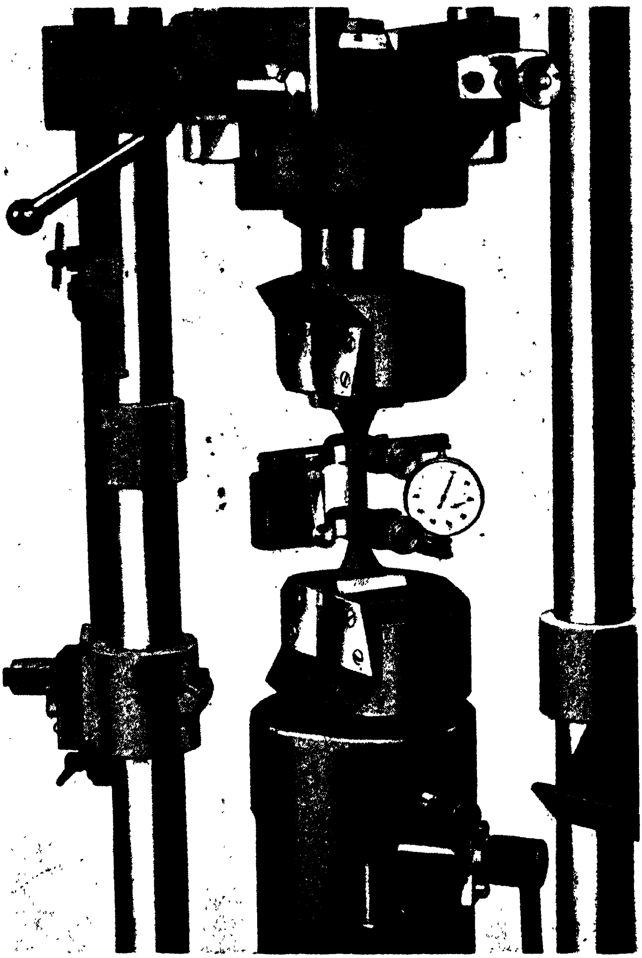


Fig. 203.—LINDLEY EXTENSOMETER IN POSITION
(*By courtesy of W. & T. Avery, Ltd.*)

piece is revolved at this speed until failure takes place. Upon failure of the test piece, the steelyard drops and cuts out the motor by means of the mercury switch. A counter is positioned on the motor shaft and records the revolutions of the test piece, from which number the reversals of stress or endurance are obtained.

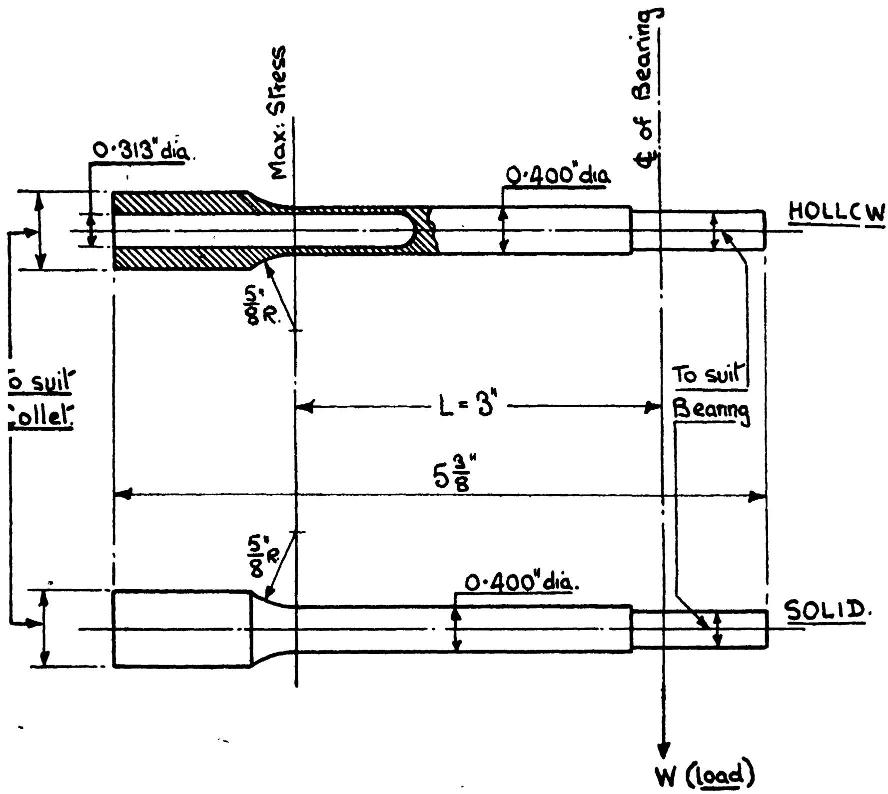


Fig. 204.—HOLLOW AND SOLID WOHLER TEST PIECES

Another test is performed with a second test piece subjected to slightly less stress and the endurance again obtained. Tests are continued with diminishing stresses until, for the solid test piece, the latter stands up to 12,000,000 reversals.

The endurance limit for ferrous metals for general purposes can be taken as the maximum stress at which the test piece remains unbroken after 10,000,000 reversals.

The results of the test can be plotted, the vertical ordinate representing either maximum stress or range of stress, and the horizontal ordinate, the endurance. A typical graph is shown in Fig. 206, and from this the

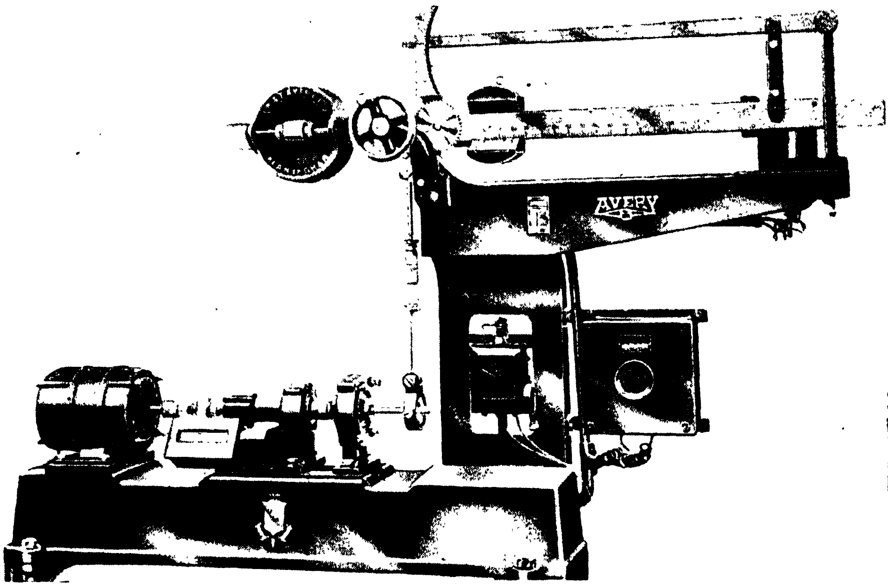


Fig. 205.—AVERY FATIGUE TESTING MACHINE (WOHLER SYSTEM)
(*By courtesy of W. & T. Avery, Ltd.*)

point at which the curve has become horizontal is where the endurance has become infinitely large, and the stress at this point is the endurance limit. If the vertical ordinate represents the range of stress and the horizontal ordinate the alternation of stress, this point is the limiting range of stress, or the fatigue range.

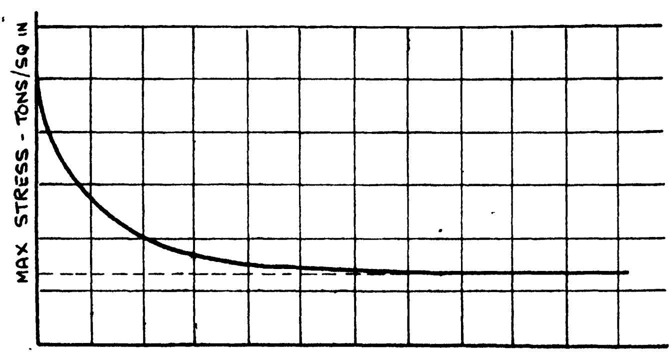


Fig. 206.—STRESS-ENDURANCE DIAGRAM

Chapter XVI

HARDNESS TESTING

THE majority of hardness tests relate to the resistance which any particular material offers to indentation. There are several methods of producing the indentation, of which the Brinell is the most widely used and will therefore receive the most consideration.

The method devised by J. A. Brinell, a Swedish engineer, consists of pressing a steel ball of given diameter into the material under a fixed load.

The Brinell Hardness Number (B.H.N.) (Fig. 207) is a standard by which the hardness of materials can be compared, and is the quotient of the applied load, in kilogrammes, divided by the spherical area of the impression produced, measured in square millimetres. The spherical area of the impression, or indentation, is calculated from its diameter :

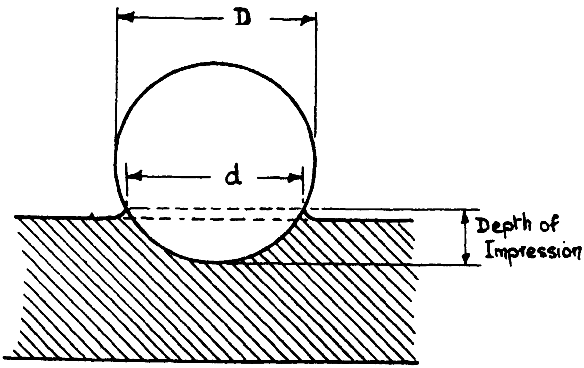


Fig 207.—THE BRINELL IMPRESSION

$$\text{Brinell Hardness No.} = \frac{\text{Load in kilogrammes}}{\text{Spherical area of indentation in sq. mm.}}$$

$$= \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)}$$

where P = Standard load in kilogrammes.
D = Diameter of ball in millimetres.
d = Diameter of indentation in millimetres.

The depth of the indentation can be obtained from :

$$\text{Depth} = \tfrac{1}{2}\left(D - \sqrt{D^2 - d^2}\right) \text{ mm.}$$

The latter value is not used in hardness tests, and the B.S.S. No. 240 states that the spherical area must be calculated from the average diameter of the indentation and not from the depth.

Brinell Hardness Numbers are usually obtained from prepared charts, and relate to the diameter of the indentation as measured by a microscope. A chart is given on page 199, by permission of Messrs. W. & T. Avery, Ltd., for tests using a 10-mm. ball and loads of 500, 1,000, and 3,000 kilos. Charts for other conditions can be found in B.S.S. No. 240. It has been found that the hardness number varies with the load and ball diameter, giving the constant :

$$\frac{P}{D^2} = \text{Constant}$$

The B.S.I. has standardised the constant for different materials, and the size of the ball indenters. The P/D^2 values are :

Steels, and materials of similar hardness	30
Copper and aluminium alloys	10
Copper and aluminium	5
Lead and tin	1

The standard ball indenters are 1, 2, 5, and 10 mm. The standard Brinell test for steel is through the medium of a 10-mm. ball, and loaded to 3,000 kilos to the specimen for 15 secs.

The application of the P/D^2 value and the ball diameter to this test is :

$$\frac{P}{D^2} = \frac{3{,}000}{10^2} = 30$$

The load is found from :

$$P = D^2 \times \text{constant} ;$$

Giving : $P = 10^2 \times 30 = 3{,}000$ kilos.

The time of application of load is, for steel 15 secs. minimum, but for softer materials, where $P/D^2 = 10$ or less, it is maintained for 30 secs.

The surface of the specimen must be flat and carefully prepared and finally polished with grade " 000 " emery paper. The flat face each side of the impression should not be less than 2 *d*. Thickness of a soft material should not be less than ·32 in. and for a hardened material ·063 in. Very hard materials should not be tested by the Brinell method.

Converting B.H. Numbers to Approximate Tensile Strengths

Brinell found that, with steel having less than ·8 per cent. carbon, there is a definite relationship between the B.H.N. and the maximum tensile strength. Factors for conversion are to be found in B.S.S. No. 240, and for carbon steels can be taken as B.H.N. $\times$ ·23 = approximate tensile strength in tons/sq. in. :

$$\frac{\text{Ultimate tensile stress tons/sq. in.}}{\text{B.H.N.}} = \cdot 23$$

Alloy steels (heat-treated to 60 tons/sq. in.) Constant ·22.
Alloy steels (heat-treated to 100 tons/sq. in.) Constant ·21.

The Avery Patent Hardness Testing Machine (Brinell) (No. 691) (Figs. 208 and 209)

The construction of the machine is similar to that of a platform weighing machine. The seating A, on which the specimen is placed, is

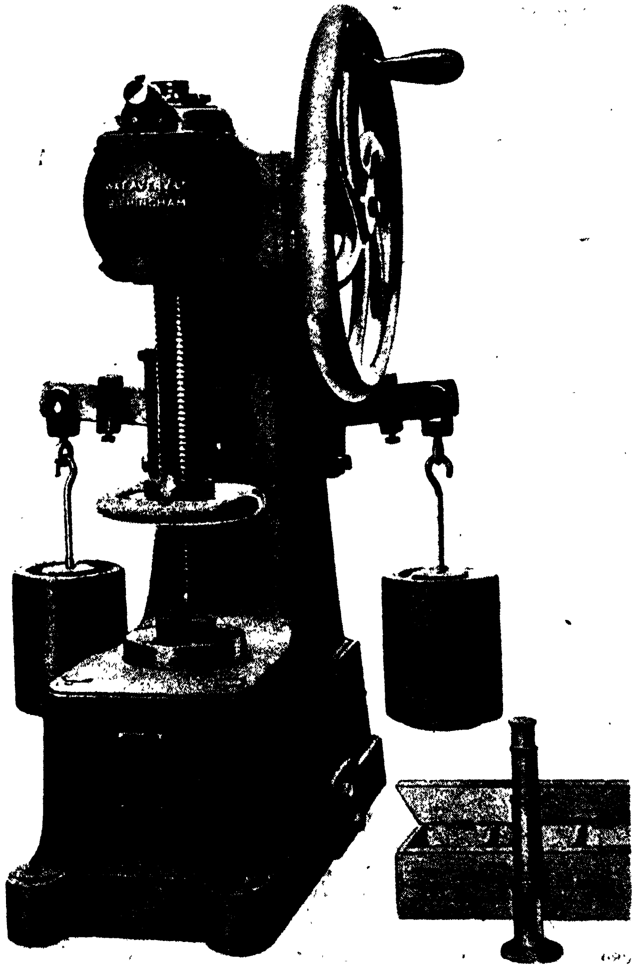


Fig. 208.—AVERY PATENT HARDNESS TESTING MACHINE (BRINELL), NO. 691
(*By courtesy of W. & T. Avery, Ltd.*)

supported by a lever B in the base of the machine by means of hardened-steel knife-edges and bearings. This lever in turn is connected to a transfer lever C, at the end of which is a tension rod D connecting the

two steelyards *E*. Pressure applied to the seating *A* is transmitted by means of accurately gauged levers to the weighing steelyards, on which the load is balanced by means of the proportional weights. The steel ball through which the load is applied is fitted at *F*, and the load gradually applied by means of the handwheel *G*, through a worm drive. The ball can quickly be set in contact with the specimen before making a test by releasing the catch *H* and turning the screw by means of the handwheel *J*.

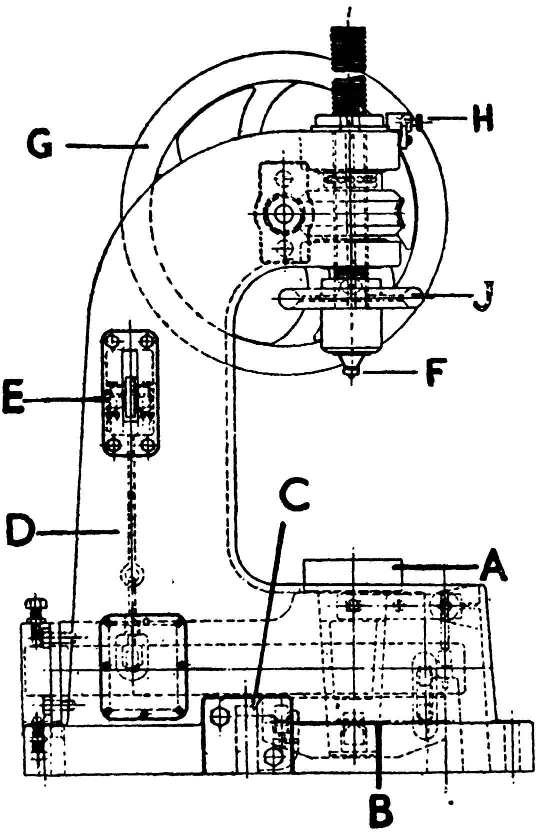


Fig. 209.—Diagrammatic view of Brinell machine
(*By courtesy of W. & T. Avery, Ltd.*)

Split weights and extra ball holders can be supplied which are easily interchangeable and give the following tests :

3,000 kilos. with 10-mm. ball.
1,000 kilos. with 10-mm. ball.
500 kilos. with 10-mm. ball.
750 kilos. with 5-mm. ball.
120 kilos. with 2-mm. ball.
30 kilos. with 1-mm. ball.

Method of Making a Test.—Place the specimen on the seating *A*, and bring the ball *F* almost into contact with the surface of the specimen by turning the handwheel *J*, as described before. Replace the catch *H* in position, and turn the handwheel *G* a few times until the steelyards rise to a horizontal position. After the prescribed time period, release the pressure by turning the handwheel *G* in the opposite direction and measure the diameter of the impression by means of the microscope.

Microscope.—When in use, the micrometer is placed over the impression, as illustrated in Fig. 210, and the focus is adjusted as found necessary. Readings can be taken to ·05 mm. A special high magnification microscope is used with 1-mm. and 2-mm. balls.

Table of "Brinell" Hardness Numerals
Diameter of Steel Ball = 10 mm.

Dia. of Ball Impression mm.	Hardness Number for a Load of Kgs.			Dia. of Ball Impression mm.	Hardness Number for a Load of Kgs.			Dia. of Ball Impression mm.	Hardness Number for a Load of Kgs.			Dia. of Ball Impression mm.	Hardness Number for a Load of Kgs.		
	3000	1000	500		3000	1000	500		3000	1000	500		3000	1000	500
2·00	945	315	158	3·30	341	114	56·8	4·60	170	56·8	28·4	5·90	99·2	33·1	16·5
2·05	899	300	150	3·35	331	110	55·1	4·65	167	55·5	27·8	5·95	97·3	32·4	16·2
2·10	856	285	143	3·40	321	107	53·4	4·70	163	54·3	27·1	6·00	95·5	31·8	15·9
2·15	817	272	136	3·45	311	104	51·8	4·75	159	53·0	26·5	6·05	93·7	31·2	15·6
2·20	780	260	130	3·50	302	101	50·3	4·80	156	51·9	25·9	6·10	92·0	30·7	15·3
2·25	745	248	124	3·55	293	97·7	48·9	4·85	152	50·7	25·4	6·15	90·3	30·1	15·1
2·30	712	237	119	3·60	285	94·9	47·5	4·90	149	49·6	24·8	6·20	88·7	29·6	14·8
2·35	682	227	114	3·65	277	92·3	46·1	4·95	146	48·6	24·3	6·25	87·1	29·0	14·5
2·40	653	218	109	3·70	269	89·7	44·9	5·00	143	47·5	23·8	6·30	85·5	28·5	14·2
2·45	627	209	104	3·75	262	87·2	43·6	5·05	140	46·5	23·3	6·35	84·0	28·0	14·0
2·50	601	200	100	3·80	255	84·9	42·4	5·10	137	45·5	22·8	6·40	82·5	27·5	13·7
2·55	578	193	96·3	3·85	248	82·6	41·3	5·15	134	44·6	22·3	6·45	81·0	27·0	13·5
2·60	555	185	92·6	3·90	241	80·4	40·2	5·20	131	43·7	21·8	6·50	79·6	26·5	13·3
2·65	534	178	89·0	3·95	235	78·3	39·1	5·25	128	42·8	21·4	6·55	78·2	26·1	13·0
2·70	514	171	85·7	4·00	229	76·3	38·1	5·30	126	41·9	20·9	6·60	76·8	25·6	12·8
2·75	495	165	82·6	4·05	223	74·3	37·1	5·35	123	41·0	20·5	6·65	75·4	25·1	12·6
2·80	477	159	79·6	4·10	217	72·4	36·2	5·40	121	40·2	20·1	6·70	74·1	24·7	12·4
2·85	461	154	76·8	4·15	212	70·6	35·3	5·45	118	39·4	19·7	6·75	72·8	24·3	12·1
2·90	444	148	74·1	4·20	207	68·8	34·4	5·50	116	38·6	19·3	6·80	71·6	23·9	11·9
2·95	429	143	71·5	4·25	201	67·1	33·6	5·55	114	37·9	18·9	6·85	70·4	23·5	11·7
3·00	415	138	69·1	4·30	197	65·5	32·8	5·60	111	37·1	18·6	6·90	69·1	23·0	11·5
3·05	401	134	66·8	4·35	192	63·9	32·0	5·65	109	36·4	18·2	6·95	68·0	22·7	11·3
3·10	388	129	64·6	4·40	187	62·4	31·2	5·70	107	35·7	17·8	7·00	66·8	22·3	11·1
3·15	375	125	62·5	4·45	183	60·9	30·5	5·75	105	35·0	17·5				
3·20	363	121	60·5	4·50	179	59·5	29·8	5·80	103	34·3	17·2				
3·25	352	117	58·6	4·55	174	58·1	29·1	5·85	101	33·7	16·8				

Rockwell and Avery Direct-reading Rapid-hardness Testing Machines (Fig. 211)

In these machines, the hardness value is directly indicated on a dial, and is measured by the depth of penetration produced by the major load. The total depth of penetration is not used; an initial or minor load is first applied to eliminate surface imperfections, followed by the major load, being the sum of the initial and subsequent loads.

There are two standard forms of indenters, the $\frac{1}{16}$-in. diameter ball for use on cast iron, unhardened steel, brass, bronze, etc., and the diamond cone, having a cone angle of 120° with spherical tip ground to ·2 mm. radius and used on hardened steel.

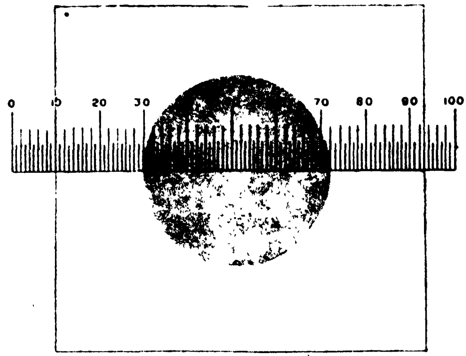


Fig. 210.—Brinell impression seen through microscope

(*By courtesy of W. & T. Avery, Ltd.*)

The minor and major loads are applied by means of deadweights acting through an accurate weighing lever fitted with hardened-steel knife-edges.

The dial carries two scales, the B scale used when testing with a $\frac{1}{16}$-in. ball indenter, and the C scale when testing with a 120° diamond cone. In each case, an initial or minor load of 10 Kg. is applied when the specimen is brought into contact with the indenter. The major load for the B scale in conjunction with a $\frac{1}{16}$-in. ball indenter is 100 Kg., and for the C scale in conjunction with the diamond cone 150 Kg. Other loads are used for special purposes.

To Make a Test.—The specimen is placed on the anvil and brought into contact with the indenter by means of the capstan handwheel; elevation is continued until the small pointer on the dial stands approximately at the dot. At this stage a minor load of 10 Kg. has been applied, and the large pointer is approximately vertical. The dial bezel is turned to set the scale zero in line with the pointer. The zero line is marked with a small arrow. The crank handle is now pushed back to release and apply the major load. The pointer will move in an anti-clockwise direction, and upon coming to rest the crank handle is pulled forward and the major load released, the minor load still being retained. The Rockwell hardness number is now read off the scale.

Tables are available for converting Rockwell to Brinell Hardness Numbers.

Alloy sheet or strip usually needs no preparation for testing, but other specimens should be machine finished and polished with grade "000" emery paper.

The Vickers Diamond-Pyramid Hardness Test

The Vickers Diamond-Pyramid Hardness Test is similar in principle to the Brinell method from which it has been evolved. The B.H. numbers are not comparative, i.e. a B.H.N. of 248 is not half as hard as a B.H.N. of 496, and in order that comparative tests could be made, the

V.D.P. method was devised. By maintaining a constant angle on the indenter—and it should be noted that any angle would suffice—as used

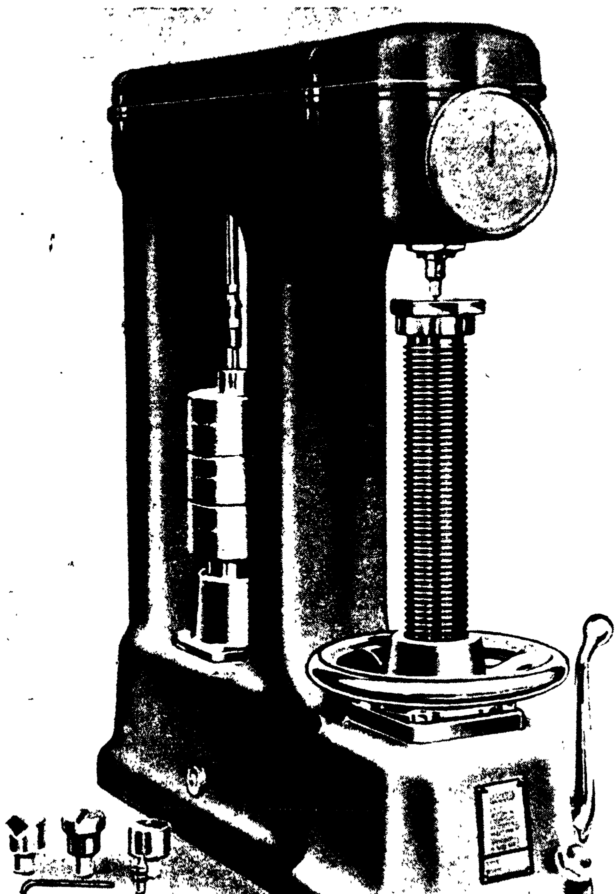


Fig. 211.—Avery direct reading rapid hardness testing machine
(*By courtesy of W. & T. Avery, Ltd.*)

in the Vickers test would give a proportional relationship. The angle of 136° has been standardised because of its relationship to the Brinell impression.

The indenter for this test is in the form of a diamond pyramid having a 136° angle of indentation. The diamond can be employed on the

hardest steels without deformation and give a clear geometrical shape, whatever the depth.

By using a diamond having a constant angle, and giving no deformation under load, a proportional relationship is obtained ; thus, a material of 496 hardness will be twice as hard as one of 248 hardness.

The hardness number is in accordance with the Brinell principle, and is calculated from :

$$\text{Diamond Hardness Number} = \frac{\text{Load in Kgs.}}{\text{Area of indentation in sq. mm.}}$$

This can be expressed as $= \dfrac{2P \sin \frac{\phi}{2}}{d^2}$

where P = Load in Kilogrammes.
ϕ = Angle between each pair of opposite faces of the pyramid.
d = Mean diagonal of impression in mm.

The range of load (B.S.S. No. 427) is 5, 10, 20, 30, 50, 100, and 120 Kg. ; the greatest load possible should be employed to ensure the highest degree of accuracy. This load is decided upon consideration of sizes and material. The average period of application is 30 secs.

The Vickers and Brinell Hardness values on steel are practically the same up to 300 B.H.N., but over this hardness there is a steady fall of the Brinell below the Vickers number, and above 600 the Brinell number is unreliable.

Load is applied by means of a weight-operated cam, maintained for the predetermined period and then released. The microscope is positioned immediately over the square impression, focused, and the measurement of the diagonal between the knife-edges automatically recorded on a counter (Fig. 212). The other diagonal can be checked by turning the microscope head through 90°, and should there be any variation in measurement, the mean dimension is taken.

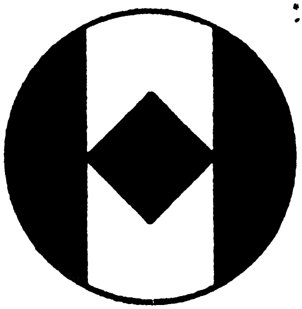


Fig. 212.—VICKERS DIAMOND IMPRESSION AS SEEN THROUGH MICROSCOPE

Brinell tests for light loads can be carried out by substituting a 1- or 2-mm. ball and holder to replace the diamond. The loads used under these conditions must comply with the Brinell standard.

The test specimen must be flat and have a highly polished surface, and the thickness, as recommended by the B.S.I., at least $1\frac{1}{2}$ times the diagonal of the impression.

The Edgwick Visual Hardness Testing Machine, No. 1414 (Fig. 213).

This machine can be used for either Brinell or Vickers tests, and for production or single tests.

The loading speed is controlled by a single screw which operates an

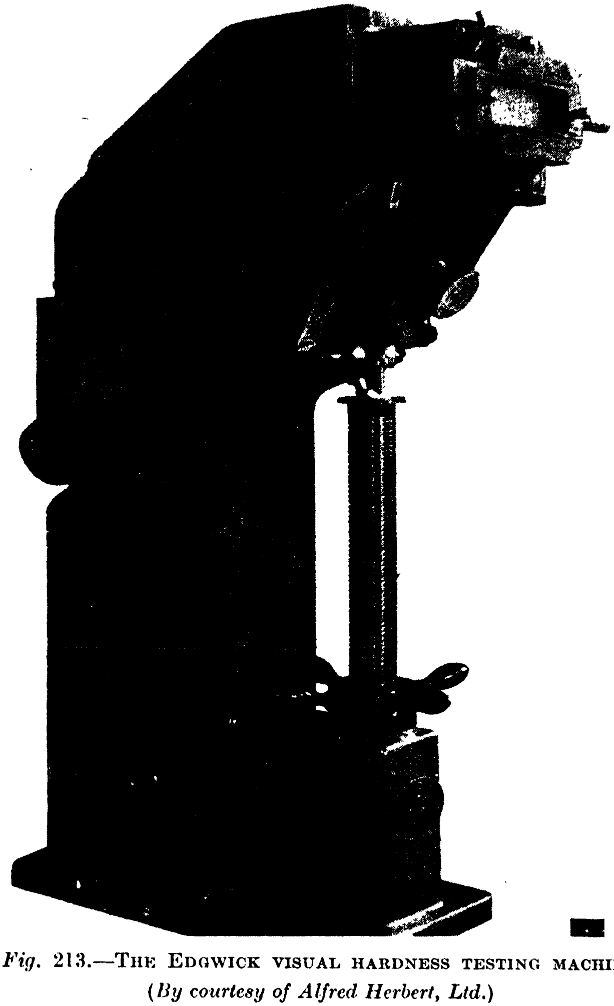


Fig. 213.—THE EDGWICK VISUAL HARDNESS TESTING MACHINE
(*By courtesy of Alfred Herbert, Ltd.*)

oil brake. The usual load period is 15 secs., but can be much less for production tests, which can attain a rate of up to 600 per hour. It is recommended that the minimum duration for Brinell Nos. 100 to 150 should be 5 secs., 150 to 200 3 secs., and 200 and upwards 1 sec. Alteration in loading is effected by moving a finger-operated stop to the load

indicated on a scale at the side of the machine. The loading range is from ·977 to 187·5 Kg. Loading and unloading, adjusting the indenter to the component, and swinging back the indenter to use the projection apparatus are all effected by a single lever.

The projector magnifies the impression of the ball or diamond pyramid and projects it on to the screen. For production work, tolerance lines on a ground-glass screen are provided. For single tests, the actual size of the image is measured. The scale of the screen is in $\frac{1}{10}$ mm. and $\frac{1}{100}$ mm. and the micrometer gives readings of $\frac{1}{1000}$ mm. The screen is rotatable, so that when a Vickers pyramid is used, the two diagonals of the impression can be measured.

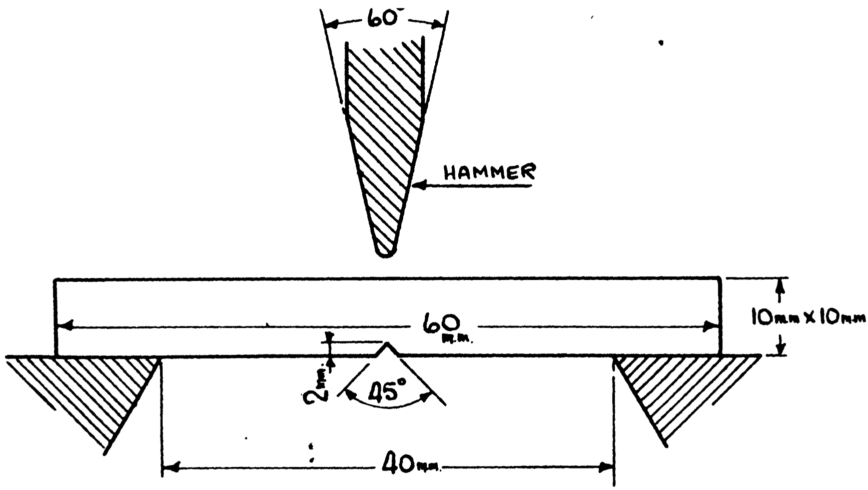


Fig. 214.—CHARPY OR BEAM TEST PIECE

Clamping mechanism is provided for light or heavy specimens, and the equipment includes balls of ·625 mm., 1·25 mm., 2·5 mm., and 5 mm. diameter and a Vickers 136° surface angle diamond.

Impact, or Notched-bar Testing

The majority of D.T.D. and B.S. Specifications for steel require that under test the steel must give a specified Izod value. This value is obtained from the impact or notched-bar test.

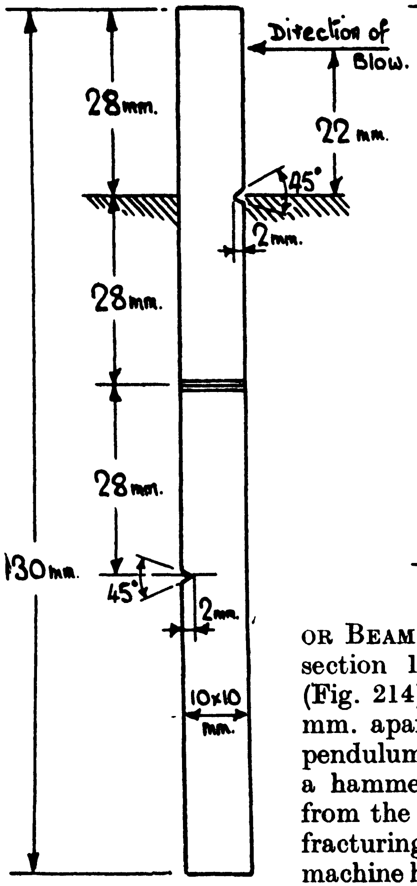
This test is used mainly to determine whether the microstructure of the material has been adversely affected by heat treatment. Any particular material, providing the heat treatment is satisfactory, will give a certain impact or Izod value. The tensile test will often show very similar results for two specimens heat treated differently, but the Izod test will give two distinct values.

The test is also used to determine the capability of a certain material

to resist the formation and spreading of cracks. A satisfactory test will show a high Izod value.

A brittle material will give a very low Izod value, but it does not follow that a material having a high impact value will be more resistant to shock. The method of impact loading is employed only as a means of conducting the test, and is the outcome of experiments by Izod, Charpy, and others.

It should be noted that Izod values are only comparable with materials of the same composition ; the value for carbon steel cannot be compared with the value for nickel steel.



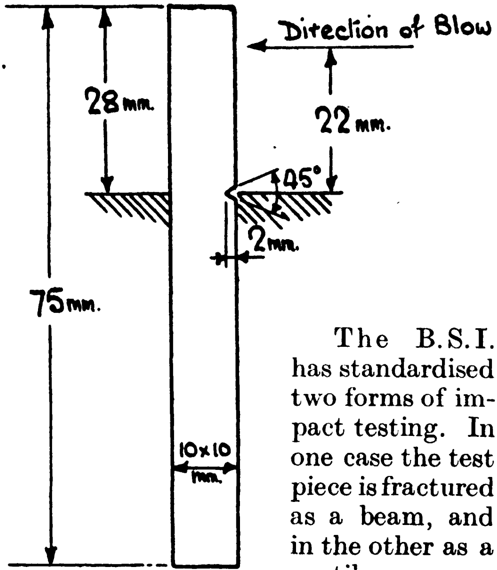


Fig. 215.—IZOD OR CANTILEVER TEST PIECES

The B.S.I. has standardised two forms of impact testing. In one case the test piece is fractured as a beam, and in the other as a cantilever.

THE CHARPY OR BEAM METHOD.—The test piece has a cross section 10 mm. × 10 mm. and 60 mm. long (Fig. 214). It is held in cast-iron supports 40 mm. apart on the two uprights of the Charpy pendulum machine. The test piece is struck by a hammer as shown, and the value obtained from the energy absorbed from the hammer in fracturing the test piece. The small type of machine has a striking energy of about 217 ft./lb.

THE IZOD OR CANTILEVER METHOD.—The standard test pieces have a cross section of 10 mm. × 10 mm., and a length of 75 mm. or 130 mm. according to whether one or three notches are provided. The standard test pieces are shown in Fig. 215, and the position of the

notches must be as shown. For the standard test these notches must be cut at right angles to the direction of rolling. The same proportions for the notches are used for both Charpy and Izod test pieces (Fig. 216), and are — 45° angle 2 mm. deep and ·25 mm. root radius. The position of the test piece and notch, when gripped in the vice of the testing machine, should be noted.

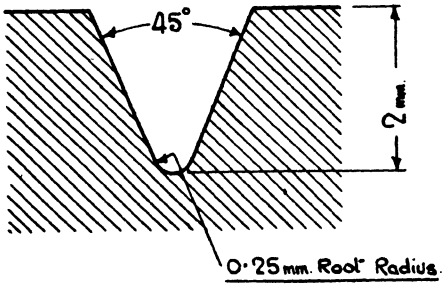


Fig. 216.—NOTCH PROPORTIONS

The Avery "Izod" Impact Testing Machine (Fig. 217)

The machine consists of two rigid "A" frames bolted to a heavy base. The pendulum arm is pivoted at the top of the "A" frames, and is mounted on ball bearings. A hardened-steel knife-edge is fitted at the side of the pendulum, and strikes the test piece at the position shown in Fig. 215. The test piece is held in the vice "cantilever manner."

A graduated quadrant is fitted at the apex of the "A" frames, over which the loose pointer, actuated by the pendulum, moves and indicates the Izod value in ft./lb. The striking velocity of the pendulum, as specified by the B.S.I., is not less than 3 metres per second. The machine has a capacity of 120 ft./lb.

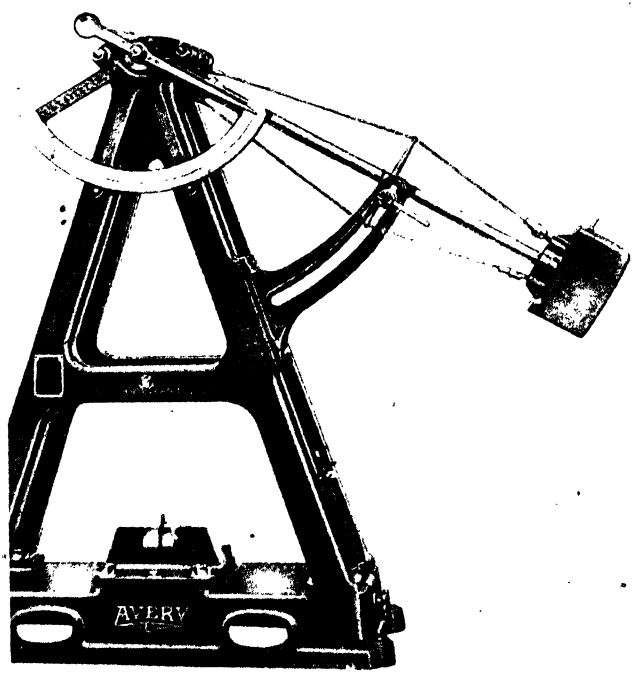


Fig. 217.—"IZOD" IMPACT TESTING MACHINE

(*By courtesy of W. & T. Avery, Ltd.*)

Chapter XVII

AERONAUTICAL INSPECTION

AERONAUTICAL inspection practice is carried out to the requirements of the Air Ministry and the organisation of the A.I.D. functions under a most comprehensive system. Provision is made for the inspection of each component and assembly during the various stages of production, from the raw material to the finished product.

Reference will be found in this chapter to the various Inspection Leaflets, and these can be found in the Air Ministry Handbook for Civil Aircraft obtainable from H.M. Stationery Office. This work should be consulted, especially by Aircraft Inspectors, who desire to become more fully conversant with the Air Ministry's requirements than is possible within the limits of this chapter.

Materials

The Air Ministry require that " All materials used in the construction of aircraft shall be in accordance with the specifications approved for the type design, and every batch of such material shall be proved to comply with such specifications by suitable examination, sampling and testing by approved methods." (Inspection Leaflets 117, 410, 411 and 412.)

Classification of Steels

The majority of steels used in aircraft and aero engine construction can be grouped under the following general headings :—

(1) Carbon Steels (including mild, medium and high carbon steels according to the carbon content).

(2) Alloy Steels (e.g., nickel 3 to 4·5%, chromium 0·5 to 1·5%). This group can be subdivided into medium high tensile and high tensile steels according to the composition and heat treatment.

(3) Stainless Steels. (These can be subdivided into the standard 12% chromium, the " Two-score " and the austenitic classes of non-corrodible steels.) Further reference should be made to Inspection Leaflet 430.

Inspectors' Stamps

Every inspector is provided with stamps carrying the identity of the individual inspector and with which he must mark the materials or

components which he is called upon to inspect. In this connection the Air Ministry requires that the inspector must be satisfied that—

(*a*) the material complies with the requirements specified on the approved drawings, and has received the requisite process treatment.

(*b*) the part is dimensionally accurate and satisfactory as regards its finish.

(*c*) the material has not been subjected to any improper treatment and is free from defects.

"The inspector must also satisfy himself that all detail parts are properly fitted and secured during the assembly of an aircraft, and finally, that the complete aircraft is in all respects airworthy."

The types of stamps, markings and position on details will be found in Inspection Leaflets 18 and 128.

INSPECTION OF AIRCRAFT TIMBER

Before being passed to the shops for the manufacture of aircraft main structural members, i.e., solid or laminated spars, flanges and webs of built-up spars, longerons; undercarriage, interplane, fuselage and wing compression struts, all timber must be tested for—

(1) freedom from brittleness.
(2) the correct moisture content.
(3) the specified density.

Subsidiary timber parts need not be subjected to these tests, but must be visually inspected for quality and freedom from deleterious defects on completion of manufacture. In instances where both grades are used simultaneously, definite identification markings on the higher grade timber is essential.

Test for Brittleness

METHOD A.—The test piece is cut parallel to the grain, 12 in. long by 1 in. square, and the sides cut radially and tangentially. The blow shall be applied in the tangential direction. The Testing Machine (Fig. 218) consists of a freely falling, vertically guided weight of 24 lb., the striking surface of which is cylindrical, with a radius of 3 in. The weight is dropped through 6·5 in. on to the test piece when the latter is placed centrally on supports 10 in. apart. The supports have a ¼ in. radius on the inside upper edges. The test piece is required to withstand one blow of 13 ft.-lb. without showing signs of tension failure on the vertical sides. Should this test not be conclusive the test piece should be subjected to a further blow of half the previous energy, i.e., 6·5 ft.-lb. The opening out of a few fibres on the tension side is not taken as indicative of failure.

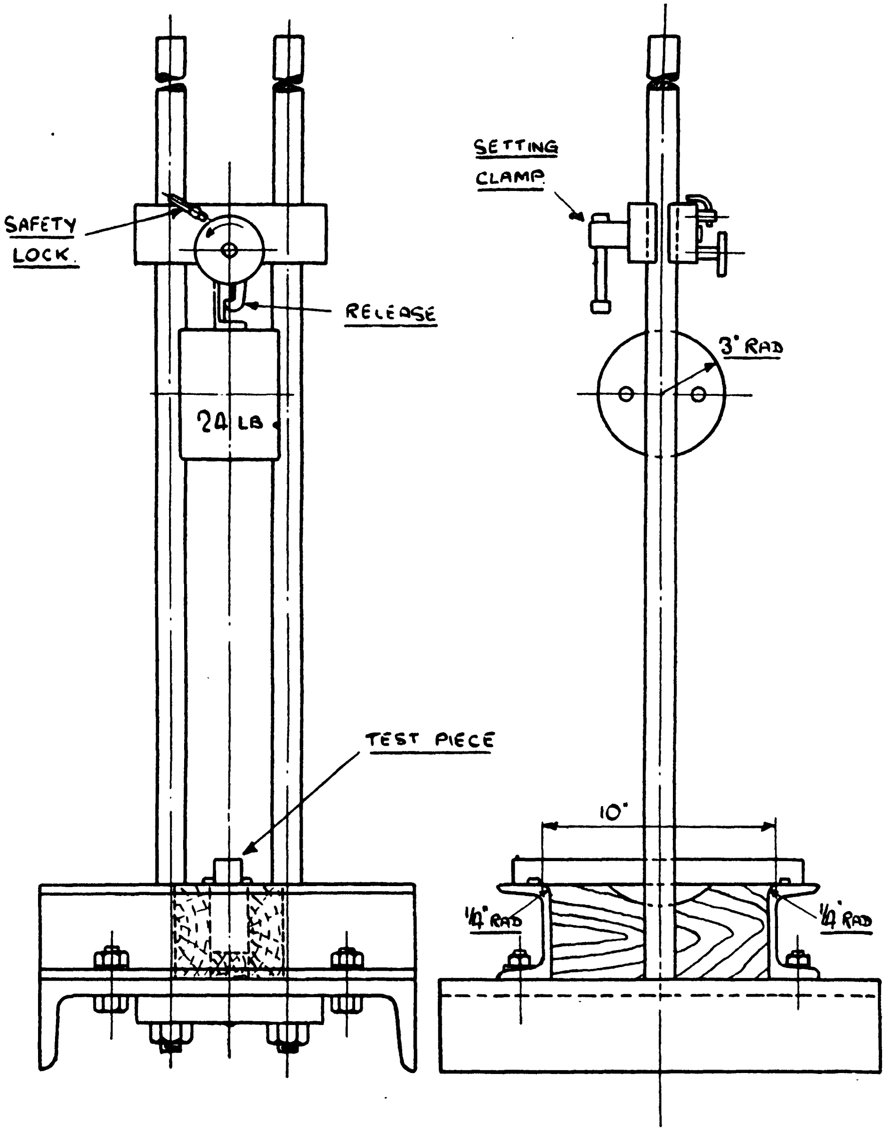


Fig. 218.—Drop impact testing machine

Method B.—The test piece is notched, and the sides cut radially and tangentially as shown in Fig. 219, and is broken by impact in a testing machine of the type shown in Figs. 220 and 221. The test piece must absorb not less than 6 ft.-lb. and a tolerance of —0·5 ft.-lb. allowed

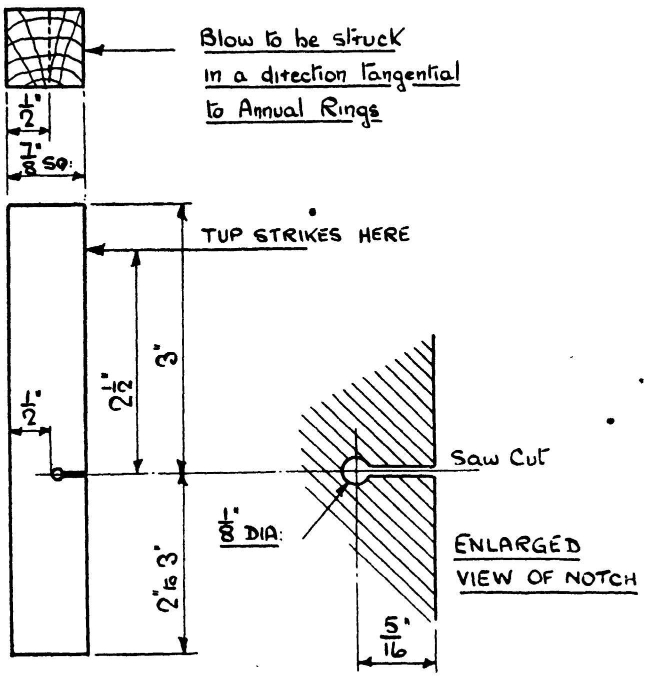


Fig. 219.—STANDARD TEST PIECE

at the discretion of the inspector provided that the fractured specimen shows a satisfactory amount of fibre.

Moisture Content

There are two methods of determining the moisture content of timber. Firstly, a small block of the test specimen is split into small pieces approximately the size of a match stick and weighed on an approved hydrometer. Alternatively, a specimen $\frac{1}{4}$ in. in thickness is cut in a direction transverse to the grain and weighed on an approved chemical balance. The specimen is then dried in a suitable oven maintained at a temperature of 221° F. until two successive weighings are identical. The moisture content is calculated from—

$$\text{percentage of moisture} = \frac{W_1 - W_0}{W_0} \times 100.$$

Where W_1=original weight of specimen
W_0=weight after desiccation.

Every precaution must be taken to prevent change in moisture content between cutting the specimen and the first weighing, or between removal from the oven and subsequent weighing. The moisture content should be 15%, but must not exceed 17%.

Determination of Density

The density is determined by taking a sample from the plank and weighing and measuring the volume. The result should not be less than that stated in the table to be found in Inspection Leaflet No. 7.

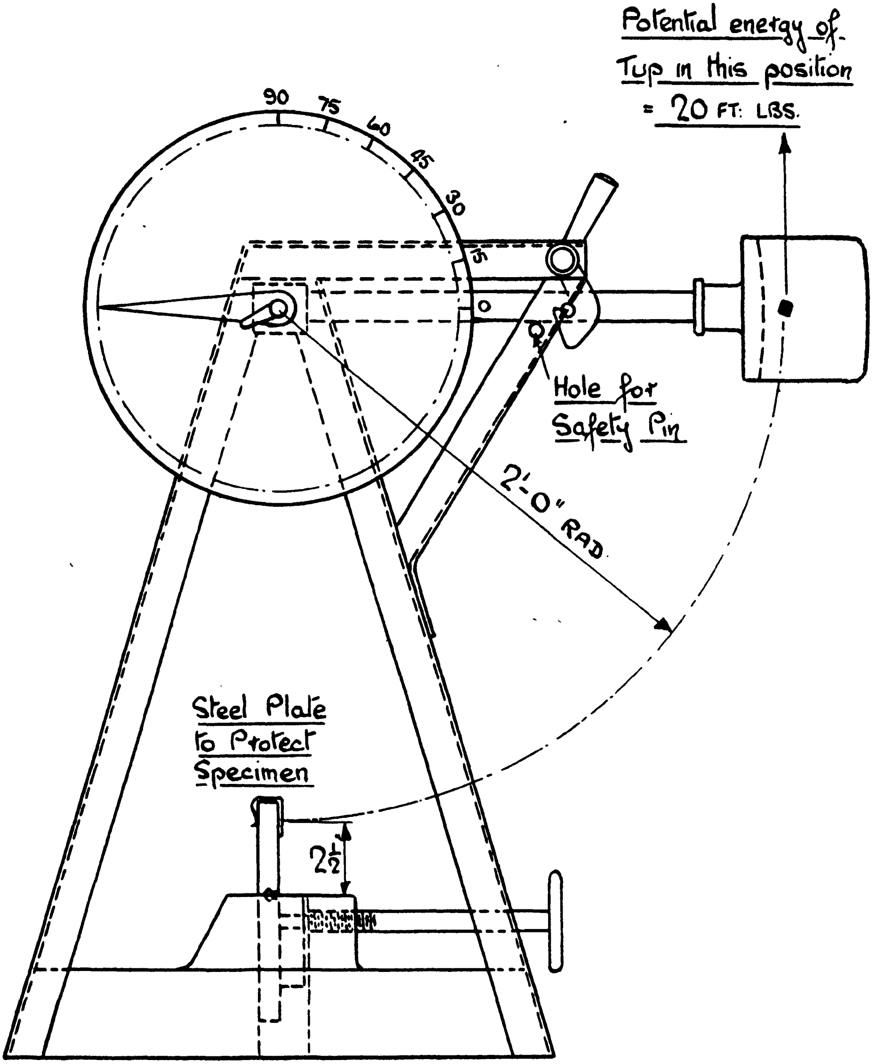


Fig. 220.—IMPACT TESTING MACHINE

Additional tests which are sometimes required are—

(*a*) Young's Modulus of Elasticity and Modulus of Rupture.
(*b*) Compression Strength.

Young's Modulus of Elasticity

The type of machine used for the determination of Young's Modulus

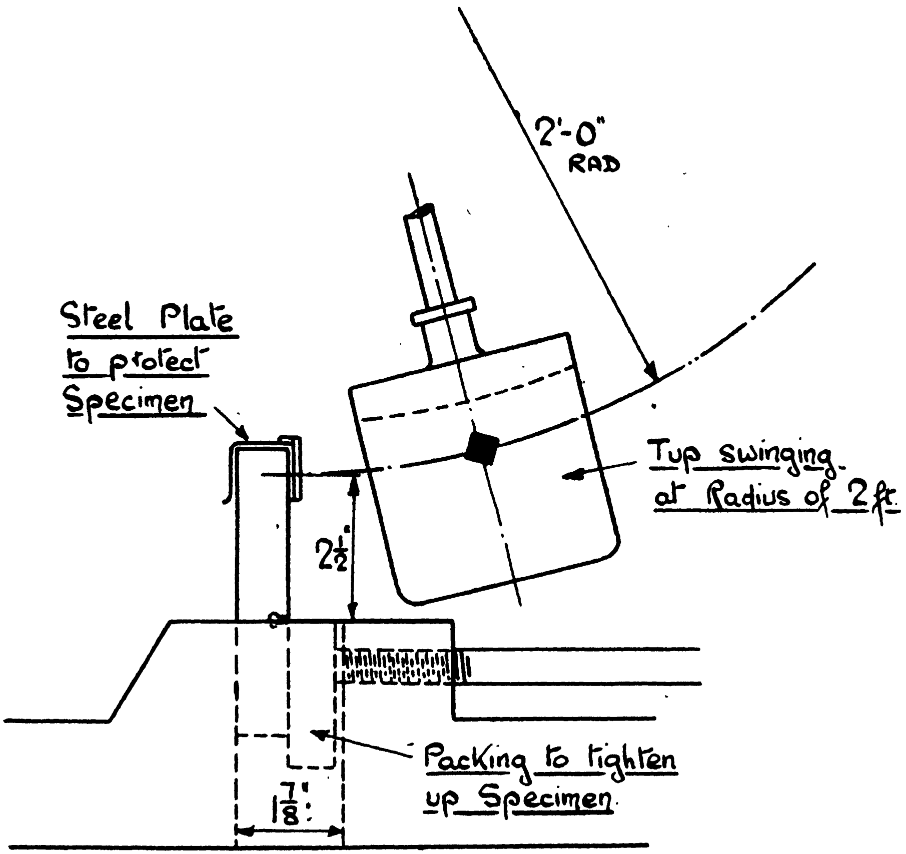


Fig. 221.—Enlarged view showing specimen in position in testing machine

of Elasticity is shown in Fig. 222. The method of loading Fig. 223 is termed "four point loading," and is standardised by the B.S.I.

Two sizes of test pieces have been standardised, 40 in. long by 2 in. deep by 1 in. wide, or 40 in. long by 2 in. deep by 2 in. wide, the latter being preferable. The length should be cut parallel with the grain and the depth preferably parallel with the radial face of the test piece, the heart side being uppermost.

The load should be applied in the neutral plane of the beam and in such a manner as to prevent longitudinal loading of the test piece and local crushing of the timber. The loading head should descend at a constant speed of $0{\cdot}13 \pm 20\%$ in. per minute.

The test is performed by taking a series of deflections over a range of

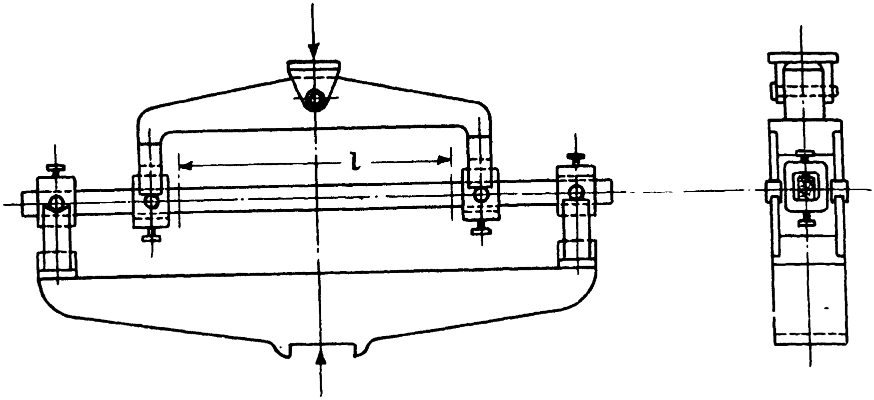


Fig. 222.—BEAM TEST MACHINE

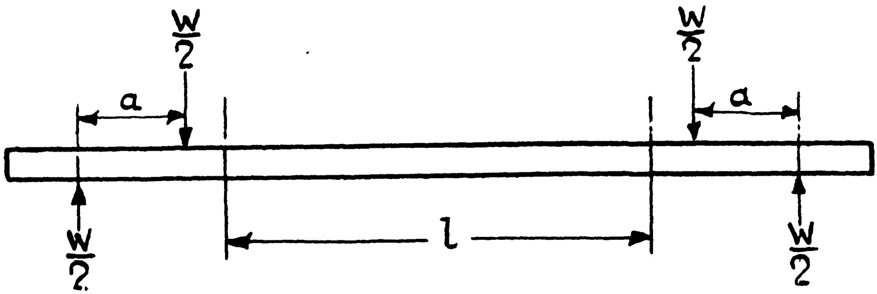


Fig. 223.—FOUR POINT LOADING DIAGRAM

increasing loads, and measured on a portion of the test piece between the inner loading points. A satisfactory test will show, when plotted, a straight line up to the elastic limit.

Young's Modulus is obtained from—

$$E = \frac{3(W_1 - W_2)}{4(d_1 - d_2)} \times \frac{al^2}{bh^3}$$

To apply this formula, any two points in the straight line portion of the graph are taken and the loads represented by W_1, W_2, and the corresponding deflections by d_1, d_2, and—

a = distance between outer support and inner loading point.
b = breadth of test piece.
h = depth of test piece.
l = length (of the neutral axis) at the centre of which deflection has been measured.

The sizes for a, b, h, l being given in inches.

Modulus of Rupture

The formula is—

$$\text{Modulus of Rupture} = \frac{3Wa}{bh^2}$$

Where W is the load required to break the test piece.

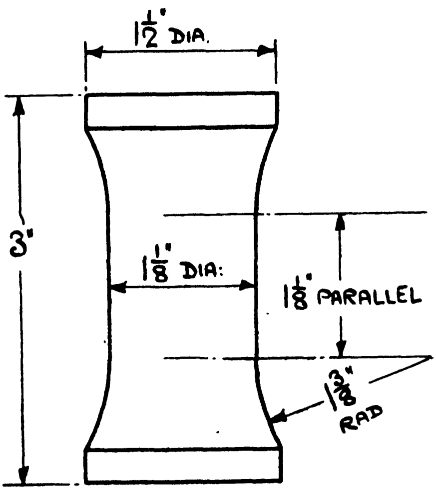


Fig. 224.—British Std. End-grain Compression Test Piece

End Grain Compression Strength

The test pieces required can be cut 1 in. square by 2 in. long or of turned cylindrical form as shown in Fig. 224. In the latter case, the pips must be removed and the ends turned truly flat. Three test pieces are taken from each plank to be tested.

The load is applied through the compression platens of a testing machine so that the stress in the test piece increases at a rate of from 3,000 to 6,000 lb. per square inch per minute. The resulting ultimate compression stress is taken as the average of the three tests.

INSPECTION OF PLYWOOD

British made plywood is grouped under two headings—

(1) for use in structurally important parts;
(2) for use in subsidiary parts.

Plywood classified under the first heading is subjected to a detailed process inspection to ensure that both outer and inner veneers are of the specified timber and comply with the specification requirements; the cement is correctly applied to the veneers; records are maintained showing the press gauge recordings and the period the boards are retained in the press; each board is stamped with its batch number immediately upon being withdrawn from the press; ventilation, temperature and humidity are maintained during the drying operation and that the edges of each board are trimmed square.

Plywood classified under the second heading is subjected to a visual examination of each finished board to verify that the plies are securely cemented together; the plywood is flat, free from blisters, buckling and

other surface defects and that the edges of the boards have been trimmed square.

Imported Plywood

In this case where no detailed process inspection is possible, the inspection for structurally important parts consists of :—Examination of the inner plies to verify freedom from timber defects, absence of gaps and overlapping joins, etc. Each finished board is checked dimensionally and for compliance with specification requirements with regard to joins, flatness and freedom from manufacturing defects.

Re-Tests

Three or multi-ply which has been previously accepted as complying with the requirements of B.S.S.4V.3 and has been stored for twelve months or a longer period must not be used for aircraft construction until a re-test from each batch verifies that the timber still complies with the requirements of the specification.

In each of the foregoing cases, representative samples must be submitted to an approved test house for verification to specification requirements. (Inspection Leaflet 41.)

INSPECTION OF WOODEN AIRSCREWS

It is the duty of the inspector to verify that the airscrew is manufactured to the drawing and/or design requirements and that all material employed in the manufacture conforms to that specified. The process inspection is taken in the following order :—

Laminæ

Verification to drawing and storage conditions prior to working. Moisture content tests. Jointing as specified and checking thickness to ensure correct number of laminations in finished airscrew.

Assembly of Laminæ and Cementing

Prior to assembly all laminæ must have been stored for the specified period and under the correct atmospheric conditions. Other points to be observed are temperature of cementing room according to the particular adhesive, selection and arrangement of laminæ, surfaces of laminæ to be clean and correctly toothed and an approved method of clamping employed, flat base to be provided for support over the length of the airscrew and only approved cements are used.

Rough Shaped Block

Prior to rough shaping the waiting period must be allowed. On completion of rough shaping, boring and drilling, the inspector must

verify that only approved laminæ have been used, the assembly and cementing processes have been satisfactorily performed and that the block is free from timber and joint defects.

Inspection in the White

This follows the final shaping and consists of verifying that the correct period has elapsed between rough and final shaping, satisfactory cemented joints and the timber free from defects. Also a dimensional check is required and that the airscrew is within the limits for balance.

The remainder of the necessary inspection covers the finishing processes such as cellulose lacquer, fabric covering and sheathing, and finishing with the final inspection. (Inspection Leaflet 12.)

Gluing of Structurally Important Parts

The process of gluing must be done under approved conditions and, apart from seeing that these conditions are maintained, the inspector is limited to a visual examination. (Inspection Leaflet 435.)

ANODIC OXIDATION PROCESS

This process is employed for the protection of aluminium and its alloys, including duralumin. Inspection consists of a general examination of the plant and the methods of its operation, periodic tests of the electrolyte and visual examination of the finished parts.

The parts must be cleaned with petrol, benzol or solvent naphtha and finally washed with hot water and dried immediately prior to treatment in the oxidation bath. The chloride content of the electrolyte must not exceed the equivalent of ·20 grm. sodium chloride per litre and must consist of a solution (using distilled water) containing 3% of chromic acid.

After treatment the parts must be thoroughly washed in hot water and then dried. (Inspection Leaflet 8.)

ELECTRO-DEPOSITED ZINC AND CADMIUM COATINGS

These coatings are employed for the protection of standard aircraft steel parts. Inspection consists of a general examination of the plant and the methods of its operation, the method adopted to remove brittleness and physical tests to ensure compliance with specification requirements.

All rust, grease and other foreign matter must be removed before plating.

For zinc electro-deposition a suitable bath can be made up of the following composition :—

6 oz. potassium or sodium cyanide ;
12 oz. zinc cyanide ;
4 oz. caustic soda ;
1 gallon of water.
Suitable agents may be added if required.

The anodes must be of zinc. The current density for the bath should be from 2 to 4 amp. per square foot of cathode surface at a pressure of from 3 to 5 volts. Normal temperature will give a good deposit, but a more efficient result is obtained if the bath is used at a temperature of 40° C.

For cadmium electro-deposition a suitable bath can be made up as follows :—

1½ to 3 oz. cadmium cyanide ;
5 to 10 oz. sodium or potassium cyanide ;
1 gallon of water.
Suitable "addition" agents may be added if required.

The anodes should generally be of cast cadmium and the current density of the bath approximately 10 amp. per square ft. of cathode surface at a pressure of from 2 to 5 volts.

After plating, the parts must be thoroughly washed in hot water and then heated for not less than 30 minutes to a temperature between 100° C. and 200° C. This latter operation is performed to remove brittleness.

The obvious result of plating is an increase in the dimensions of the parts treated, and the inspector must check to determine any variation from the allowable tolerances. The Air Ministry specify a thickness for coatings of zinc and cadmium of ·0003 in. minimum, and the following method of determining the thickness of the coating on a plated part. The plated part of known weight and area is degreased by a suitable warm solvent vapour treatment and totally immersed in a solution of freshly prepared ammoniacal ammonium persulphate, containing 5% aqueous solution of ammonium persulphate, to which is added 10% by volume of concentrated ammonia solution (sp. g. ·880). The solution is stirred occasionally until the coating is completely dissolved, taking approximately 30 minutes. The part is then removed, washed, dried and re-weighed. The thickness of coating is calculated from—

$$\textit{For Cadmium } T = \frac{W}{A \times 141}$$

where T = Thicksnes in inches.
W = Weight of coating in grams.
A = Area of coating in square inches.

And for zinc, the formula is—

$$\text{Zinc } T = \frac{W}{A \times 113}$$

(Inspection Leaflet 53.)

CORROSION-PREVENTING PROCESSES

Corrosion-preventing processes vary according to the particular metals to be coated. The following list covers, generally, the processes for aircraft metallic parts :—

Ferrous Alloys

(*a*) Varnishes and enamels.
(*b*) Electro-deposition of metals having corrosion-resisting properties.
(*c*) A combination of (*a*) and (*b*).

The varnishes and enamels in general use are—Stoving Enamel D.T.D. Specn. 56A, Cellulose Enamel D.T.D. Specn. 63 and Pigmented Oil Varnish D.T.D. Specn. 62. The two methods of electro-deposition are zinc and cadmium; these have already been considered under Electro-deposited Zinc and Cadmium.

In addition to the foregoing are also certain proprietary processes.

It is the inspector's responsibility in the case of varnishes and enamels to verify that the particular coating to be used meets the requirements of the relevant specification, to ensure that the parts to be coated are properly treated before processing and that the correct procedure during the actual processing is strictly maintained.

In the case of proprietary processes, the inspector must ensure that the instructions issued upon installation of the plant are observed, particular attention being paid to temperature control to ensure that the mechanical properties of the particular material being coated are not adversely affected. The minimum thickness of the coating must not be less than ·0003 in.

Aluminium and Aluminium Alloys

The normal treatment is the anodic method as previously described· This can be followed by stove enamelling, cellulose enamelling, pigmented oil varnish or the application of lanoline.

Magnesium Alloys

The procedure consists firstly of the preparation of the surfaces of the parts to be treated. Where the parts are not machined to very fine tolerances they are dipped for 15 seconds in a 10% solution of sulphuric, or nitric acid and then examined. The dipping process is repeated until the surface is uniformly clean, and then the part is finally washed in cold water. Where parts are machined to very fine limits, the surface

is prepared by immersion for two hours in a solution containing 2% caustic soda at boiling temperature. In the case of castings which are to be partly machined to very fine limits the procedure is—clean in an acid bath by dipping for 15 seconds in a solution containing 10% sulphuric, or nitric acid and wash in hot water, machine to size and immerse for two hours in a solution containing 2% caustic soda at boiling temperature.

After surface preparation, the parts are immersed in a chromate bath containing 1·5% potassium bichromate, 1% potassium alum and ·5% caustic soda. The parts are immersed for six hours at boiling temperature, removed and washed in running hot water, dried and examined. The final treatment consists of either (1) the application of Sozol; (2) a temporary rust preventative to D.T.D. Specn. 121A; (3) at least two coats of a cellulose enamel to D.T.D. Specn. 63.

The inspector is required to ensure that the processes are carried out in the prescribed manner, and that the immersion baths contain the specified constituents and that the strength is maintained.

Brass and Bronze Alloys (Marine)

The treatment in this case is either stoving enamel, cellulose enamel or pigmented oil varnish.

Metallisation Process

This is a patent process and consists of spraying the part to be treated with molten aluminium. The aluminium is alloyed to the steel by suitable heat treatment. The Air Ministry specify this process for the treatment of exhaust manifolds and stub pipes only.

The surfaces for metal spraying are first prepared by sandblasting; the sand specified is washed and crushed black flint sand. During this process a gauge pressure of between 27 and 30 lb. should be maintained, and the sand applied with the jet from 5 to 7 in. from the part. It is important that, after sandblasting and prior to metallising, the parts are handled with clean rubber gloves, and not with unprotected hands. The parts are examined after sandblasting and must be free from rust, grease, scale or moisture. Should oil or moisture be detected the parts should be heated to 120° C. and re-sandblasted.

The actual process of spraying is accomplished by means of a wire-fed gas-heated metal spraying pistol. Commercially pure aluminium, 1 mm. diameter, is used and fed at approximately 15 ft. per minute, the pistol being held from 3 to 5 in. from the work. The deposit should have a thickness of at least ·007 in. and a weight of at least 1½ oz. per square foot.

Next, the parts are coated with bitumastic paint and placed in a muffle or semi-muffle type of furnace which has been heated up to 800° C.

The heat is shut off and the temperature allowed to drop to 650° C. or for 20 minutes, whichever period is shorter. The parts are then taken out of the furnace and allowed to cool in air.

The final process consists of burnishing the parts by means of revolving brushes having steel wire bristles of 36 S.W.G. Surfaces inaccessible to the wire brush are carefully hand-scratched.

Stoving Enamelling

The two types of stoving enamel as specified by the Air Ministry are—

(1) Normal type to D.T.D. Specn. 56 (latest issue). The stoving temperature not to exceed 170° C.

(2) "Low-temperature" type to D.T.D. Specn. 235 (latest issue). The stoving temperature not to exceed 125° C.

For light alloy fittings and components, only the low-temperature type is permissible.

The inspector must ensure that the enamel complies with the relevant specification and that the process is carried out to the Air Ministry's requirements.

DOPING

Two types of dope are generally available—

(*a*) Normal.

(*b*) Anti-chill.

The inspector is required to ensure that an approved dope is applied in accordance with the manufacturer's instructions. (Inspection Leaflet 421.)

RIVETING PROCESSES

The importance of inspection of riveted joints cannot be overstressed, especially for aircraft work. The types of rivet generally used in aircraft construction are solid, tubular, cup or balloon and pop or pierced rivets.

To ensure an efficient joint the inspector must satisfy himself that the holes are drilled clean and correct dimensionally, both for diameter and pitch. Burrs must be removed from each hole and any swarf present removed from the surfaces to be riveted. The rivets must conform to the drawing and/or specification requirements and be of such fit in the holes as to allow the correct clearance. Where heat treatment is specified for the rivets, the inspector must ensure that the operation has been satisfactorily carried out. The subject of riveting processes is comprehensively dealt with in Inspection Leaflet 24, including illustrations showing typical examples of defective riveting.

WELDING OF AIRFRAME AND AERO ENGINE PARTS

The importance attached to the operation of welding can be assessed by the fact that the Air Ministry require that the inspector ensures that, except in cases where the parts have not been stressed when considering design or affect safety, all persons engaged in performing the welding operations shall have been proved competent. To satisfy this requirement standard test specimens of prescribed form and dimensions are required to be made up by each welder and submitted to A.I.D. Test House No. 2, Cardington, for satisfactory report.

The materials to be welded must be approved by the inspector, who also must ensure that the actual welding process is performed to the requirements of the Air Ministry.

The inspection of finished welds consists mainly of a visual examination and reliance has to be placed on the following approved conditions :—(*a*) Use of approved materials ; (*b*) the approval and maintenance of the standard of efficiency of the welders ; (*c*) the use of approved methods. (Inspection Leaflet 39.)

SOFT SOLDERING

This is the process of joining two metal parts by means of another metal or alloy having a lower melting point. The parts to be joined must first be very thoroughly cleaned, preferably by mechanical means. Pickling in a dilute acid bath must only be resorted to in special circumstances and after immersion be thoroughly cleansed of all traces of acid by washing in boiling water and the parts afterwards heated to a temperature of 150° C.

After cleaning, the parts are tinned and the flux applied before being placed together for soldering. Except in certain cases, soldering solution to D.T.D. Specn. 81 or any other suitable flux may be employed with lead/tin solder. The former soldering solution or resin is suitable for use with cadmium zinc solder.

For the actual operation of soldering, a soldering iron is generally employed ; an acetylene flame is prohibited.

The solder must be of the correct grade as specified in B.S. Specn. No. 219, or as a substitute for soft solder cadmium-zinc solder to D.T.D. Specn. 221 is approved.

Finally, after soldering, the joint should be wiped clean and washed in hot water. The latter does not apply when resin has been used as a flux. Where paste fluxes have been used the joint must be cleaned with petrol before washing.

A special process is required in the case of stainless steel and this is given below.

Soft Soldering of Stainless Steel

Cleaning of the parts consists of anodic pickling in an aqueous solution, one-third (by volume) concentrated sulphuric acid and 2½%

potassium dichromate. An alternate method is pickling in a solution of 50% hydrochloric acid for not more than 5 or 6 minutes.

The parts must be thoroughly washed in clean water and surface brushed after removal from the acid bath. Tinning can now proceed.

A satisfactory flux for all grades of stainless steel, applied undiluted and for use with either grade " A " or " B " solder to B.S. Specn. No. 219 is ortho-phosphoric acid.

The parts must be washed in hot water to remove all traces of flux after soldering.

Brazing

Dip brazing is preferable for aero parts and consists of immersing the parts in a bath of molten spelter consisting of 55% copper and 45% zinc, which is heated to a maximum temperature of 900° C.

When the previous method is impracticable a brazing metal having a melting point of approximately 900° C. is used, and must comply with grade " A " metal to B.S. Specn. No. 263. Parts made of steel must be tempered after brazing at a temperature of 650° C.

Silver Soldering

As the name suggests, silver solder contains silver in addition to copper and zinc, and must comply with B.S. Specn. No. 206. A suitable flux is calcined borax, and the parts to be joined are first fastened with binding wire or weights. A red heat is necessary for satisfactory processing.

In all cases of soldering and brazing, inspection of the finished component cannot be generally accepted as conclusive, and it is essential that the inspector should apply a detailed process examination. (Inspection Leaflet 405.)

Stelliting

Stellite is used for facing valves, valve seats and rockers owing to its great resistance to wear and oxidation. The principal constituents are chromium, cobalt and tungsten.

The process is comparable with that of high-temperature brazing except that the layer of stellite is applied to the particular part by means of an oxy-acetylene torch. Care must be taken to ensure that fusion does not occur. Heat treatment can be applied to remove any stresses set up during the process.

The inspector must verify the composition of the stellite, supervise heat treatment when applied and examine after rough grinding for cracks, blowholes, etc.

After final grinding, an area on each part overlapping the stellited surface is etched and inspected for cracks and general condition. Except

in the case of low tensile steels, the parts are tempered to remove brittleness due to the etching process. The final inspection operation is a dimensional check. (Inspection Leaflet 400.)

WHITE METALLING OF BEARINGS

This process is of extreme importance as the efficiency of the engine is largely dependent upon the white metalling of the bearings. It is essential that the white metal complies with the correct specification.

The shell into which the white metal is poured must first be cleaned to remove all traces of oil and grease. This is accomplished by immersing the bearing in boiling caustic soda for 15 to 20 minutes and washing in clean boiling water.

Prior to the actual white metalling the surface on which the metal is to be cast must be tinned. It is necessary to ensure that the tinning will not adhere other than at this particular part of the shell. As a precaution against the foregoing, all other surfaces are painted with Hall's Distemper, or some similar composition, and allowed to dry. Before tinning, the surfaces must be cleaned with an approved flux. The latter operation is followed by immersion in a suitable bath maintained at the correct temperature. The shell upon reaching the temperature of the bath must be removed, fluxed, re-heated and rubbed over with a stick bearing the tinning medium until the whole surface is evenly covered.

A metalling jig is provided as a mould for the white metal. Prior to running the white metal, both the shell and jig are raised to the correct temperature and only sufficient white metal heated up to cover the immediate requirements. The temperature of the molten metal is generally between 350° and 450° C., according to the brand of metal used. It is essential to skim and stir the molten metal thoroughly immediately before pouring. After pouring, the metal is puddled with a length of steel wire to assist the escape of any trapped gases and ensure freedom from blowholes.

There are three methods of adhesion testing—

(*a*) The ringing test.—Applied to bearings in which the white metal is not keyed to the shell. The bearing is balanced on the fingers and tapped with a light hammer to test for true ring.

(*b*) Hot oil test.—This test is applied after rough machining and the bearing immersed in hot oil, and while still hot, wiped dry and dusted with french chalk. The bearing is allowed to become quite cold and then examined for lack of adhesion. The latter is evident by the discoloration of the chalk where oil has oozed from the bearing during cooling.

(*c*) Chipping test.—One bearing is selected from approximately every twenty cast and by means of a $\frac{3}{16}$ in. cross-cut cold chisel,

chipping out the white metal. A sound bearing will be proved if grooves can be cut through the white metal and into the base metal. If unsound the white metal will freely part from the base to which it has been cast.

(Inspection Leaflet 138.)

Hardness Testing of Metallic Materials

This subject has been fully dealt with in Chapter 16 and the conditions and methods described therein, applicable to aeronautical inspection. (Inspection Leaflet 406.)

Heat Treatment and Mechanical Testing

This subject has been already dealt with in Chapters 14 and 15. Further reference should be made to Inspection Leaflets 407, 408, 414 and 426.

DETERMINATION OF PROOF STRESS

The British Standard Specification for ·1% proof stress has already been given in Chapter 15. Suppose a ·1% proof stress is required and the standard gauge length of 2 in. is employed, then during test it is the stress at which a permanent extension of ·002 in. is obtained. (·1% of 2 in. equals ·002 in.)

A further definition can be stated—proof stress is that stress at which on a stress/strain or load/elongation diagram the curve departs by a specified percentage of the gauge length from the straight line of proportionality.

The requirements of certain B.Std. and D.T.D. Specifications for ascertaining proof stress are :—

(1) For one test sample from each cast, the proof stress shall be ascertained from an accurately determined load/elongation diagram.

(2) For all remaining test samples, the proof stress shall be ascertained by an approved method.

Load/Elongation Diagram

Considering the first method, a diagram should be plotted to the largest convenient scale Fig. (225). The Air Ministry require that the vertical ordinate represents the stress and not load to ensure a constant angle for the line of proportionality for any given material. Three or four points should be sufficient to plot the line of proportionality and a similar number for the curve.

It will be observed from the diagram, that the graph does not start from zero. The reason for this is that readings of elongation at light loads are inaccurate and the material requires a tensioning stress before

settling down, therefore extensometer readings are not taken until a small initial load has been applied.

Assuming the specified amount of permanent extension for the material is ·1% of gauge length 2 in. It is necessary to find the point on the curve where there is a deviation of ·002 in. from the line of proportionality. It is only necessary to draw a line, shown chain dotted, parallel to the straight line of proportionality measured horizontally at a distance of ·002 in. The point where the chain dotted line cuts the curve will indicate the proof stress (*P* on diagram).

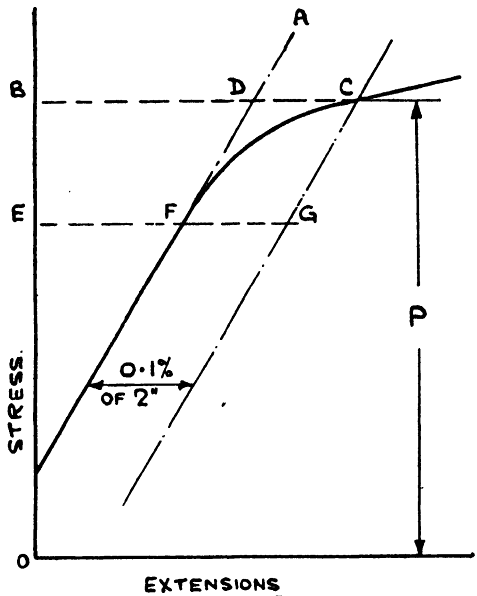


Fig. 225.—LOAD/ELONGATION CURVE FOR PROOF STRESS DETERMINATION

It would, perhaps, be advantageous at this stage to stress the fact that extensions immediately following the elastic limit are not all permanent. For the purpose of making this quite clear the additional letters *A*, *B*, *C*, *D*, *E*, *F* and *G* have been added to the diagram. The point *F* represents the elastic limit, or, to be more correct, the limit of proportionality. *EF* is the amount of elastic extension up to the limit of proportionality at stress *OE*, but *FG* is part elastic extension plus the permanent set. Comparing the foregoing with the extensions at the proof stress (*P*), *BD* is the amount of elastic extension due to the stress *OB* which is the same as *P*; *DC* is equal to the permanent extension allowed which in the case of this diagram is ·002 in. It can now be seen that the amount of elastic extension between the limit of proportionality and the proof stress is equal to *BD* minus *EF*.

Approved Methods

(1) *Permanent Extension Method.*

This method does not actually determine the value of proof stress, but in certain cases is used to verify that the material complies with proof stress requirements of the relevant specification. The procedure is—

(1) Load the specimen until the tensioning stress is reached. The latter being 20 to 25% of the specified minimum proof stress.

(2) Take the extensometer reading or alternatively set the extensometer to zero.
(3) Raise the stress to the specified minimum proof stress and hold the load for 15 seconds.
(4) Unload to slightly less than tensioning stress.
(5) Re-load to the tensioning stress.
(6) Take extensometer reading.

If the extensometer reading does not exceed the amount specified by the relevant specification the material can be accepted in compliance with the specification requirements for minimum proof stress.

The foregoing would be sufficient if a minimum value only were specified, but the specification sometimes also requires a maximum proof stress in addition.

Having ascertained that the material is satisfactory to the requirements for minimum proof stress and without re-setting the extensometer to zero proceed by repeating the operations 3 to 6, substituting the maximum proof stress value in place of the minimum value. The permanent set should not be less than specified in the relevant specification and in the event of compliance the material can be accepted as satisfactory.

(2) *Four Point Method. Fig.* (226.)

By this method, a closely approximate value can be obtained having been given the specification requirements for the upper and lower limit of proof stress (U and L on diagram). Where no upper limit is specified, this can be assumed, being based on a knowledge of the material obtained from actual testing experience and which for any given material is constant. Where it is only required to know if the proof stress is above a specified minimum value, the assumption of an upper limit is unnecessary, and the final operation (6) given later is omitted.

Referring to Fig. 226, $ABCD$ is the stress/elongation curve, the chain dotted line being drawn parallel to the line of proportionality AE and at a distance p from it, "p" representing the specified permanent extension.

The following is the sequence of operations during test, where $x = \frac{AL}{AF}$ and $y = \frac{AU}{AF}$ (AF being a fractional part of both AL and AU) in order that x and y are whole numbers :—

(1) Apply the tensioning stress OA to the specimen.
(2) Set the extensometer to zero.
(3) Increase the stress to OF.
(4) Take the reading "e."
(5) Increase the load until the extensometer reading is equal to $ex + p$.

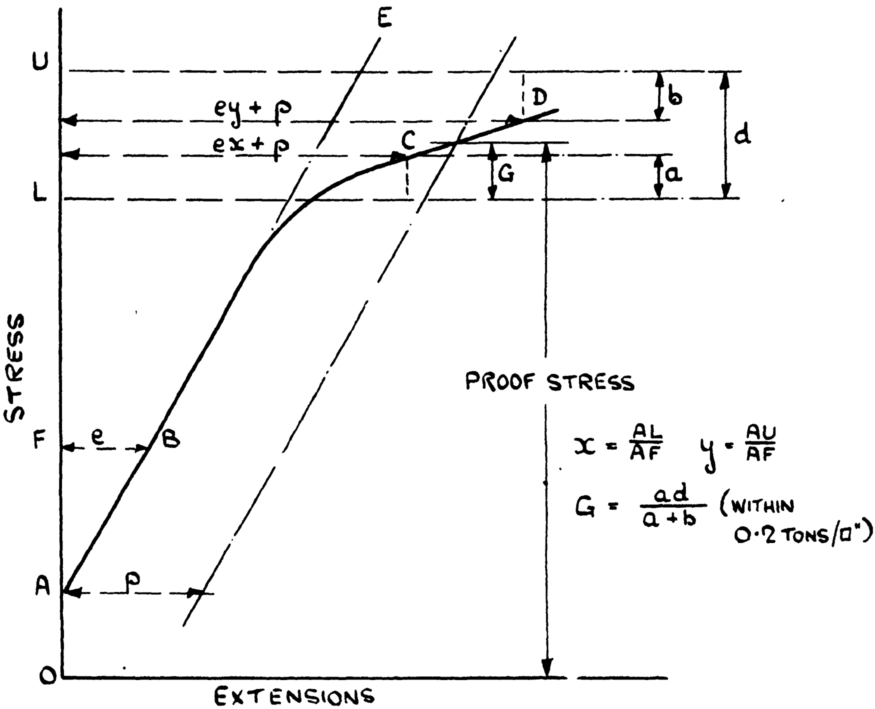


Fig. 226.—FOUR POINT METHOD OF PROOF STRESS DETERMINATION

(6) Increase the load until the extensometer reading is equal to $ey + p$.

The reading "e" for any given material will be almost constant.

The results of the test being recorded, if the stress due to the loads reached during operations 5 and 6 are above the low limit and below the high limit required to the relevant specification, the material is considered to be satisfactory as regards proof stress.

The test piece for proof stress determination should comply with the requirements of B.S. Specification 2A4, B.S. Specification 485 or relevant specification. The parallel length can be increased to suit the particular extensometer used if necessary. (Inspection Leaflet 417.)

TABLES OF NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS FROM 0° TO 90°. READ THE TABLE DOWNWARDS FOR *SINES* AND UPWARDS FOR *COSINES.*

Natural Sines

′	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	′
0	000 000	017 452	034 899	052 336	069 756	087 156	104 528	121 869	139 173	156 434	60
5	1 454	8 907	6 353	3 788	071 207	8 605	5 975	3 313	140 613	7 871	55
10	2 909	020 361	7 806	5 241	2 658	090 053	7 421	4 756	2 053	9 307	50
15	4 363	1 815	9 260	6 693	4 108	1 502	8 867	6 199	3 493	160 743	45
20	5 818	3 269	040 713	8 145	5 559	2 950	110 313	7 642	4 932	2 178	40
25	7 272	4 723	2 166	9 597	7 009	4 398	1 758	9 084	6 371	3 613	35
30	8 727	6 177	3 619	061 049	8 459	5 846	3 203	130 526	7 809	5 048	30
35	010 181	7 631	5 072	2 500	9 909	7 293	4 648	1 068	9 248	6 482	25
40	1 635	9 085	6 525	3 952	081 359	8 741	6 093	3 410	150 686	7 916	20
45	3 090	030 539	7 978	5 403	2 808	100 188	7 537	4 851	2 123	9 350	15
50	4 544	1 992	9 431	6 854	4 258	1 635	8 982	6 292	3 561	170 783	10
55	5 998	3 446	050 883	8 306	5 707	3 082	120 426	7 733	4 998	2 216	5
60	7 452	4 899	2 336	9 756	7 156	4 528	1 869	9 173	6 434	3 648	0
Cos.	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	
Sin.	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	
0	173 648	190 809	207 912	224 951	241 922	258 819	275 637	292 372	309 017	325 568	60
5	5 080	2 237	9 334	6 368	3 333	260 224	7 035	3 762	310 400	6 943	55
10	6 512	3 664	210 756	7 784	4 743	1 628	8 432	5 152	1 782	8 317	50
15	7 944	5 090	2 178	9 200	6 153	3 031	9 829	6 542	3 164	9 691	45
20	9 375	6 517	3 599	230 616	7 563	4 434	281 225	7 930	4 545	331 063	40
25	180 805	7 942	5 019	2 031	8 972	5 837	2 620	9 318	5 925	2 435	35
30	2 236	9 368	6 440	3 445	250 380	7 238	4 015	300 706	7 305	3 807	30
35	3 665	200 793	7 859	4 859	1 788	8 640	5 410	2 093	8 684	5 178	25
40	5 095	2 218	9 279	6 273	3 195	270 040	6 803	3 479	320 062	6 547	20
45	6 524	3 642	220 697	7 686	4 602	1 440	8 196	4 864	1 439	7 917	15
50	7 953	5 065	2 116	9 098	6 008	2 840	9 589	6 249	2 816	9 285	10
55	9 381	6 489	3 534	240 510	7 414	4 239	290 981	7 633	4 193	340 653	5
60	190 809	7 912	4 951	1 922	8 819	5 637	2 372	9 017	5 568	2 020	0
Cos.	79°	78°	77°	76°	75°	74°	73°	72°	71°	70°	
Sin.	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	
0	342 020	358 368	374 607	390 731	406 737	422 618	438 371	453 990	469 472	484 810	60
5	3 387	9 725	5 955	2 070	8 065	3 936	9 678	5 286	470 755	6 081	55
10	4 752	361 082	7 302	3 407	9 392	5 253	440 984	6 580	2 038	7 352	50
15	6 117	2 438	8 649	4 744	410 719	6 569	2 289	7 874	3 320	8 621	45
20	7 481	3 793	9 994	6 080	2 045	7 884	3 593	9 160	4 600	9 890	40
25	8 845	5 148	381 339	7 415	3 369	9 198	4 896	460 458	5 880	491 157	35
30	350 207	6 501	2 683	8 749	4 693	430 511	6 198	1 749	7 159	2 424	30
35	1 569	7 854	4 027	400 082	6 016	1 823	7 499	3 038	8 436	3 689	25
40	2 931	9 206	5 369	1 415	7 338	3 135	8 799	4 327	9 713	4 953	20
45	4 291	370 557	6 711	2 747	8 660	4 445	450 098	5 615	480 989	6 217	15
50	5 651	1 908	8 052	4 078	9 980	5 755	1 397	6 901	2 263	7 479	10
55	7 010	3 258	9 392	5 408	421 300	7 063	2 694	8 187	3 537	8 740	5
60	8 368	4 607	390 731	6 737	2 618	8 371	3 990	9 472	4 810	500 000	0
Cos.	69°	68°	67°	66°	65°	64°	63°	62°	61°	60°	
Sin.	30°	31°	32°	33°	34°	35°	36°	37°	38°	39°	
0	500 000	515 038	529 919	544 639	559 193	573 576	587 785	601 815	615 661	629 320	60
5	1 259	6 284	531 152	5 858	560 398	4 767	8 961	2 976	6 807	630 450	55
10	2 517	7 529	2 384	7 076	1 602	5 957	590 136	4 136	7 951	1 578	50
15	3 774	8 773	3 615	8 293	2 805	7 145	1 310	5 294	9 094	2 705	45
20	5 030	520 016	4 844	9 509	4 007	8 332	2 482	6 451	620 235	3 831	40
25	6 285	1 258	6 072	550 724	5 207	9 518	3 653	7 607	1 376	4 955	35
30	7 538	2 499	7 300	1 937	6 406	580 703	4 823	8 761	2 515	6 078	30
35	8 791	3 738	8 526	3 149	7 604	1 886	5 991	9 915	3 652	7 200	25
40	510 043	4 977	9 751	4 360	8 801	3 069	7 159	611 067	4 789	8 320	20
45	1 293	6 214	540 974	5 570	9 997	4 250	8 325	2 217	5 923	9 439	15
50	2 543	7 450	2 197	6 779	571 191	5 429	9 489	3 367	7 057	640 557	10
55	3 791	8 685	3 419	7 987	2 384	6 608	600 653	4 515	8 189	1 673	5
60	5 038	9 919	4 639	9 193	3 576	7 785	1 815	5 661	9 320	2 788	0
′	59°	58°	57°	56°	55°	54°	53°	52°	51°	50°	

Natural Cosines

TABLES OF NATURAL SINES, COSINES, TANGENTS, AND COTANGENTS FROM 0° TO 90°. READ THE TABLE DOWNWARDS FOR *SINES* AND UPWARDS FOR *COSINES.*

Natural Sines

′	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	′
0	642 788	656 059	669 131	681 998	694 658	707 107	719 340	731 354	743 145	754 710	60
5	3 901	7 156	670 211	3 061	5 704	8 134	720 349	2 345	4 117	5 663	55
10	5 013	8 252	1 289	4 123	6 748	9 161	1 357	3 334	5 088	6 615	50
15	6 124	9 346	2 367	5 183	7 790	710 185	2 364	4 323	6 057	7 565	45
20	7 233	660 439	3 443	6 242	8 832	1 209	3 369	5 309	7 025	8 514	40
25	8 341	1 530	4 517	7 299	9 871	2 230	4 372	6 294	7 991	9 461	35
30	9 448	2 620	5 590	8 355	700 909	3 250	5 374	7 277	8 956	760 406	30
35	650 553	3 709	6 662	9 409	1 946	4 269	6 375	8 259	9 919	1 350	25
40	1 657	4 796	7 732	690 462	2 981	5 286	7 374	9 239	750 880	2 292	20
45	2 760	5 882	8 801	1 513	4 015	6 302	8 371	740 218	1 840	3 232	15
50	3 861	6 966	9 868	2 563	5 047	7 316	9 367	1 195	2 798	4 171	10
55	4 961	8 049	680 934	3 611	6 078	8 329	730 361	2 171	3 755	5 109	5
60	6 059	9 131	1 998	4 658	7 107	9 340	1 354	3 145	4 710	6 044	0
Cos.	49°	48°	47°	46°	45°	44°	43°	42°	41°	40°	
Sin.	50°	51°	52°	53°	54°	55°	56°	57°	58°	59°	
0	766 044	777 146	788 011	798 636	809 017	819 152	829 038	838 671	848 048	857 167	60
5	6 979	8 060	8 905	9 510	9 871	9 985	9 850	9 462	8 818	7 915	55
10	7 911	8 973	9 798	800 383	810 723	820 817	830 661	840 251	9 586	8 662	50
15	8 842	9 884	790 690	1 254	1 574	1 647	1 470	1 039	850 352	9 406	45
20	9 771	780 794	1 579	2 123	2 423	2 475	2 277	1 825	1 117	860 149	40
25	770 699	1 702	2 467	2 991	3 270	3 302	3 082	2 609	1 879	0 890	35
30	1 625	2 608	3 353	3 857	4 116	4 126	3 886	3 391	2 640	1 629	30
35	2 549	3 513	4 238	4 721	4 959	4 949	4 688	4 172	3 399	2 366	25
40	3 472	4 416	5 121	5 584	5 801	5 770	5 488	4 951	4 156	3 102	20
45	4 393	5 317	6 002	6 445	6 642	6 590	6 286	5 728	4 912	3 836	15
50	5 312	6 217	6 882	7 304	7 480	7 407	7 083	6 503	5 665	4 567	10
55	6 230	7 114	7 759	8 161	8 317	8 223	7 878	7 277	6 417	5 297	5
60	7 146	8 011	8 636	9 017	9 152	9 038	8 671	8 048	7 167	6 025	0
Cos.	39°	38°	37°	36°	35°	34°	33°	32°	31°	30°	
Sin.	60°	61°	62°	63°	64°	65°	66°	67°	68°	69°	
0	866 025	874 620	882 948	891 007	898 794	906 308	913 545	920 505	927 184	933 580	60
5	6 752	5 324	3 629	1 666	9 431	6 922	4 136	1 072	7 728	4 101	55
10	7 476	6 026	4 309	2 323	900 065	7 533	4 725	1 638	8 270	4 619	50
15	8 199	6 727	4 988	2 979	0 698	8 143	5 311	2 201	8 810	5 135	45
20	8 920	7 425	5 664	3 633	1 329	8 751	5 896	2 762	9 348	5 650	40
25	9 639	8 122	6 338	4 284	1 958	9 357	6 479	3 322	9 884	6 162	35
30	870 356	8 817	7 011	4 934	2 585	9 961	7 060	3 880	930 418	6 672	30
35	1 071	9 510	7 681	5 582	3 210	910 563	7 639	4 435	0 950	7 181	25
40	1 784	880 201	8 350	6 229	3 834	1 164	8 216	4 989	1 480	7 687	20
45	2 496	0 891	9 017	6 873	4 455	1 762	8 791	5 541	2 008	8 191	15
50	3 206	1 578	9 682	7 515	5 075	2 358	9 364	6 090	2 534	8 694	10
55	3 914	2 264	890 345	8 156	5 692	2 953	9 936	6 638	3 058	9 194	5
60	4 620	2 948	1 007	8 794	6 308	3 545	920 505	7 184	3 580	9 693	0
Cos.	29°	28°	27°	26°	25°	24°	23°	22°	21°	20°	
Sin.	70°	71°	72°	73°	74°	75°	76°	77°	78°	79°	
0	939 693	945 519	951 057	956 305	961 262	965 926	970 296	974 370	978 148	981 627	60
5	940 189	5 991	1 505	6 729	1 662	6 301	0 647	4 696	8 449	1 904	55
10	0 684	6 462	1 951	7 151	2 059	6 675	0 995	5 020	8 748	2 178	50
15	1 176	6 930	2 396	7 571	2 455	7 046	1 342	5 342	9 045	2 450	45
20	1 666	7 397	2 838	7 990	2 849	7 415	1 687	5 662	9 341	2 721	40
25	2 155	7 861	3 279	8 406	3 241	7 782	2 029	5 980	9 634	2 989	35
30	2 641	8 324	3 717	8 820	3 630	8 148	2 370	6 296	9 925	3 255	30
35	3 120	8 784	4 153	9 232	4 018	8 511	2 708	6 610	980 214	3 519	25
40	3 609	9 243	4 588	9 642	4 404	8 872	3 045	6 921	0 500	3 781	20
45	4 089	9 699	5 020	960 050	4 787	9 231	3 379	7 231	0 785	4 041	15
50	4 568	950 154	5 450	0 456	5 169	9 588	3 712	7 539	1 068	4 298	10
55	5 044	0 606	5 879	0 860	5 548	9 943	4 042	7 844	1 349	4 554	5
60	5 519	1 057	6 305	1 262	5 926	970 296	4 370	8 148	1 627	4 808	0
′	19°	18°	17°	16°	15°	14°	13°	12°	11°	10°	′

Natural Cosines

Natural Sines (Continued)

′	80°	81°	82°	83°	84°	85°	86°	87°	88°	89°	′
0	984 808	987 688	990 268	992 546	994 522	996 195	997 564	998 630	999 391	999 848	60
5	5 059	7 915	0 469	2 722	4 673	6 320	7 664	8 705	9 441	9 872	55
10	5 309	8 139	0 669	2 896	4 822	6 444	7 763	8 778	9 488	9 894	50
15	5 556	8 362	0 866	3 068	4 969	6 566	7 859	8 848	9 534	9 914	45
20	5 801	8 582	1 061	3 238	5 113	6 685	7 953	8 917	9 577	9 932	40
25	6 045	8 800	1 254	3 406	5 256	6 802	8 045	8 984	9 618	9 948	35
30	6 286	9 016	1 445	3 572	5 396	6 917	8 135	9 048	9 657	9 962	30
35	6 525	9 230	1 634	3 735	5 535	7 030	8 223	9 111	9 694	9 974	25
40	6 762	9 442	1 820	3 897	5 671	7 141	8 308	9 171	9 729	9 983	20
45	6 996	9 651	2 005	4 056	5 805	7 250	8 392	9 229	9 762	9 990	15
50	7 229	9 859	2 187	4 214	5 937	7 357	8 473	9 295	9 793	9 996	10
55	7 460	990 065	2 368	4 369	6 067	7 462	8 552	9 339	9 821	9 999	5
60	7 688	0 268	2 546	4 522	6 195	7 564	8 630	9 391	9 848	1·00000	0
Cos.	9°	8°	7°	6°	5°	4°	3°	2°	1°	0°	

Natural Cosines

Natural Tangents

′	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	′
0	000 000	017 455	034 921	052 408	069 927	087 489	105 104	122 785	140 541	158 384	60
5	1 454	8 910	6 377	3 866	071 389	8 954	6 575	4 261	2 024	9 876	55
10	2 909	020 365	7 834	5 325	2 851	090 421	8 046	5 738	3 508	161 368	50
15	4 363	1 820	9 290	6 784	4 313	1 887	9 518	7 216	4 993	2 860	45
20	5 818	3 275	040 747	8 243	5 775	3 354	110 990	8 694	6 478	4 354	40
25	7 272	4 731	2 204	9 703	7 238	4 821	2 463	130 173	7 964	5 848	35
30	8 727	6 186	3 661	061 163	8 702	6 289	3 936	1 652	9 451	7 343	30
35	010 181	7 641	5 118	2 623	080 165	7 757	5 409	3 132	150 938	8 838	25
40	1 636	9 097	6 576	4 083	1 629	9 226	6 883	4 613	2 426	170 334	20
45	3 091	030 553	8 033	5 543	3 094	100 695	8 358	6 094	3 915	1 831	15
50	4 545	2 009	9 491	7 004	4 558	2 164	9 833	7 576	5 404	3 329	10
55	6 000	3 465	050 949	8 465	6 023	3 634	121 309	9 058	6 894	4 828	5
60	7 455	4 921	2 408	9 927	7 489	5 104	2 785	140 541	8 384	6 327	0
Cot.	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	
Tan.	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	
0	176 327	194 380	212 557	230 868	249 328	267 949	286 745	305 731	324 920	344 328	60
5	7 827	5 890	4 077	2 401	250 873	9 509	8 320	7 322	6 528	5 955	55
10	9 328	7 401	5 599	3 934	2 420	271 069	9 896	8 914	8 139	7 585	50
15	180 830	8 912	7 121	5'469	3 968	2 631	291 473	310 508	9 751	9.216	45
20	2 332	200 425	8 645	7 004	5 517	4 194	3 052	2 104	331 364	350 848	40
25	3 835	1 938	220 169	8 541	7 066	5 759	4 632	3 701	2 979	2 483	35
30	5 339	3 452	1 695	240 079	8 618	7 325	6 214	5 299	4 595	4 119	30
35	6 844	4 967	3 221	1 618	260 170	8 892	7 796	6 899	6 213	5 756	25
40	8 350	6 483	4 749	3 157	1 723	280 460	9 380	8 500	7 833	7 396	20
45	9 856	8 000	6 277	4 698	3 278	2 029	300 966	320 103	9 454	9 037	15
50	191 363	9 518	7 806	6 241	4 834	3 600	2 553	1 707	341 077	360 680	10
55	2 871	211 037	9 337	7 784	6 391	5 172	4 141	3 313	2 702	2 324	5
60	4 380	2 557	230 868	9 328	7 949	6 745	5 731	4 920	4 328	3 970	0
Cot.	79°	78°	77°	76°	75°	74°	73°	72°	71°	70°	
Tan.	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	
0	363 970	383 864	404 026	424 475	445 229	466 308	487 733	509 525	531 709	554 309	60
5	5 618	5 534	5 719	6 192	6 973	8 080	9 534	511 359	3 577	6 212	55
10	7 268	7 205	7 414	7 912	8 719	9 854	491 339	3 195	5 447	8 118	50
15	8 920	8 879	9 111	9 634	450 467	471 631	3 145	5 034	7 319	560 027	45
20	370 573	390 554	410 810	431 358	2 218	3 410	4 955	6 876	9 195	1 939	40
25	2 228	2 231	2 511	3 084	3 971	5 191	6 767	8 720	541 074	3 854	35
30	3 885	3 910	4 214	4 812	5 726	6 976	8 582	520 567	2 956	5 773	30
35	5 543	5 592	5 919	6 543	7 484	8 762	500 399	2 417	4 840	7 694	25
40	7 204	7 275	7 626	8 276	9 244	480 551	2 219	4 270	6 728	9 619	20
45	8 866	8 960	9 335	440 011	461 006	2 343	4 042	6 126	8 619	571 547	15
50	380 530	400 646	421 046	1 748	2 771	4 137	5 867	7 984	550 513	3 478	10
55	2 196	2 335	2 759	3 487	4 538	5 933	7 695	9 845	2 409	5 413	5
60	3 864	4 026	4 475	5 229	6 308	7 733	9 525	531 709	4 309	7 350	0
′	69°	68°	67°	66°	65°	64°	63°	62°	61°	60°	′

Natural Contangents

Natural Tangents (Continued)

′	30°	31°	32°	33°	34°	35°	36°	37°	′
0	577 350	600 861	624 869	649 408	674 509	·700 208	726 543	753 554	60
5	9 291	2 842	6 894	651 477	6 627	2 377	8 767	5 837	55
10	581 235	4 827	8 921	3 551	8 749	4 551	730 996	8 125	50
15	3 183	6 815	630 953	5 629	680 876	6 730	3 230	760 418	45
20	5 134	8 807	2 988	7 710	3 007	8 913	5 469	2 716	40
25	7 088	610 802	5 027	9 796	5 142	711 101	7 713	5 019	35
30	9 045	2 801	7 070	661 886	7 281	3 293	9 961	7 327	30
35	591 006	4 803	9 117	3 979	9 425	5 430	742 214	9 640	25
40	2 970	6 809	641 167	6 077	691 572	7 691	4 472	771 959	20
45	4 938	8 819	3 222	8 179	3 725	9 897	6 735	4 283	15
50	6 908	620 832	5 280	670 285	5 881	722 108	9 003	6 612	10
55	8 883	2 849	7 342	2 394	8 042	4 323	751 276	8 946	5
60	600 861	4 869	9 408	4 509	700 208	6 543	3 554	781 286	0
Cot.	59°	58°	57°	56°	55°	54°	53°	52°	
Tan.	38°	39°	40°	41°	42°	43°	44°	45°	
0	781 286	809 784	839 100	869 287	900 404	932 515	965 689	1·000 000	60
5	3 631	812 195	841 581	871 844	3 041	5 238	8 504	002 913	55
10	5 981	4 612	4 069	4 407	5 685	7 968	971 326	005 835	50
15	8 336	7 034	6 563	6 977	8 336	940 706	4 157	008 765	45
20	790 698	9 463	9 062	9 553	910 994	3 451	6 996	011 704	40
25	3 064	821 897	851 568	882 136	3 659	6 204	9 842	014 651	35
30	5 436	4 336	4 081	4 725	6 331	8 965	982 697	017 607	30
35	7 813	6 782	6 599	7 322	9 010	951 733	5 560	020 572	25
40	800 196	9 234	9 124	9 924	921 697	4 508	8 432	023 546	20
45	2 585	831 691	861 655	892 534	4 391	7 292	991 311	026 529	15
50	4 979	4 155	4 193	5 151	7 091	960 083	4 199	029 520	10
55	7 379	6 624	6 736	7 774	9 800	2 882	7 095	032 521	5
60	9 784	9 100	9 287	900 404	932 515	5 689	1·000 000	035 530	0
Cot.	51°	50°	49°	48°	47°	46°	45°	44°	
Tan.	46°	47°	48°	49°	50°	51°	52°	53°	
0	1·035 530	1·072 369	1·110 613	1·150 368	1·191 754	1·234 897	1·279 942	1·327 045	60
5	038 549	075 501	113 866	153 753	195 280	238 576	283 786	331 068	55
10	041 577	078 642	117 131	157 150	198 818	242 269	287 645	335 108	50
15	044 614	081 794	120 405	160 557	202 360	245 974	291 518	339 162	45
20	047 660	084 955	123 691	163 076	205 933	249 693	294 406	343 233	40
25	050 715	088 127	126 987	167 407	209 509	253 426	299 308	347 320	35
30	053 780	091 309	130 294	170 850	213 097	257 172	303 225	351 422	30
35	056 854	094 500	133 612	174 304	216 698	260 932	307 158	355 541	25
40	059 938	097 702	136 941	177 770	220 312	264 706	311 105	359 676	20
45	063 031	100 914	140 282	181 248	223 939	268 494	315 067	363 828	15
50	066 134	104 137	143 633	184 738	227 579	272 296	319 044	367 996	10
55	069 247	107 369	146 995	188 240	231 231	276 112	323 037	372 181	5
60	072 369	110 613	150 368	191 754	234 897	279 942	327 045	376 382	0
Cot.	43°	42°	41°	40°	39°	38°	37°	36°	
Tan.	54°	55°	56°	57°	58°	59°	60°	61°	
0	1·376 382	1·428 148	1·482 561	1·539 865	1 600 335	1·664 280	1·732 051	1·804 048	60
5	380 600	432 578	487 222	544 779	605 526	669 776	737 883	810 252	55
10	384 835	437 027	491 904	549 716	610 742	675 299	743 745	816 489	50
15	389 088	441 494	496 606	554 674	615 982	680 849	749 637	822 759	45
20	393 357	445 980	501 328	559 655	621 247	686 426	755 559	829 063	40
25	397 644	450 485	506 071	564 659	626 537	692 031	761 511	835 400	35
30	401 948	455 009	510 835	569 686	631 852	697 663	767 494	841 771	30
35	406 270	459 552	515 620	574 735	637 192	703 323	773 508	848 176	25
40	410 610	464 115	520 426	579 808	642 558	709 012	779 552	854 616	20
45	414 967	468 697	525 254	584 904	647 949	714 728	785 629	861 091	15
50	419 343	473 298	530 102	590 024	653 366	720 474	791 736	867 600	10
55	423 736	477 920	534 973	595 167	658 810	726 248	797 876	874 146	5
60	428 148	482 561	539 865	600 335	664 280	732 051	804 048	880 727	0
′	35°	34°	33°	32°	31°	30°	29°	28°	′

Natural Cotangents

Natural Tangents (Continued)

′	62°	63°	64°	65°	66°	67°	68°	69°	′
0	1·880 727	1·962 611	2·050 304	2·144 507	2·246 037	2·355 852	2·475 087	2·605 089	60
5	887 344	969 687	057 895	152 676	254 857	365 412	485 489	616 457	55
10	893 997	976 805	065 532	160 896	263 736	375 037	495 966	627 912	50
15	900 687	983 964	073 215	169 168	272 673	384 729	506 520	639 455	45
20	907 415	991 164	080 944	177 492	281 669	394 489	517 151	651 087	40
25	914 179	998 406	088 720	185 869	290 726	404 317	527 860	662 809	35
30	920 982	2·005 690	096 544	194 300	299 843	414 214	538 648	674 622	30
35	927 823	013 016	104 415	202 784	309 021	424 180	549 516	686 527	25
40	934 702	020 386	112 335	211 323	318 261	434 217	560 465	698 525	20
45	941 620	027 799	120 303	219 918	327 563	444 326	571 496	710 619	15
50	948 577	035 257	128 321	228 568	336 929	454 506	582 609	722 808	10
55	955 574	042 758	136 389	237 274	346 358	464 760	593 807	735 093	5
60	962 611	050 304	144 507	246 037	355 852	475 087	605 089	747 477	0
Cot.	27°	26°	25°	24°	23°	22°	21°	20°	
Tan.	70°	71°	72°	73°	74°	75°	76°	77°	
0	2·747 477	2·904 211	3·077 684	3·270 853	3·487 414	3·732 051	4·010 781	4·331 476	60
5	759 961	917 991	092 983	287 949	506 656	753 882	035 778	360 400	55
10	772 545	931 889	108 421	305 209	526 094	775 952	061 070	389 694	50
15	785 231	945 905	123 999	322 636	545 733	798 266	086 663	419 364	45
20	798 020	960 042	139 719	340 233	565 575	820 828	112 561	449 418	40
25	810 913	974 302	155 584	358 001	585 624	843 642	138 772	479 864	35
30	823 913	988 685	171 595	375 943	605 884	866 713	165 300	510 709	30
35	837 020	3·003 194	187 754	394 063	626 357	890 045	192 151	541 961	25
40	850 235	017 830	204 064	412 363	647 047	913 642	219 332	573 629	20
45	863 560	032 595	220 526	430 845	667 958	937 509	246 848	605 721	15
50	876 997	047 492	237 144	449 512	689 093	961 652	274 707	638 246	10
55	890 547	062 520	253 918	468 368	710 456	986 074	302 914	671 212	5
60	904 211	077 684	270 853	487 414	732 051	4·010 781	331 476	704 630	0
Cot.	19°	18°	17°	16°	15°	14°	13°	12°	
Tan.	78°	79°	80°	81°	82°	83°	84°	85°	
0	4·704 630	5·144 554	5·671 282	6·313 752	7·115 370	8·144 346	9·514 365	11·430 05	60
5	738 508	184 804	719 917	373 736	191 246	243 449	649 348	624 76	55
10	772 857	225 665	769 369	434 843	268 726	344 956	788 173	826 17	50
15	807 685	267 152	819 657	497 104	347 861	448 957	931 009	12·034 62	45
20	843 005	309 279	870 804	560 554	428 706	555 547	10·078 93	250 51	40
25	878 825	352 063	922 832	625 226	511 318	664 822	229 43	474 22	35
30	915 157	395 517	975 764	691 156	595 754	776 887	385 40	706 20	30
35	952 013	439 659	6·029 625	758 383	682 077	891 851	546 15	946 92	25
40	989 403	484 505	084 438	826 944	770 351	9·009 826	711 91	13·196 88	20
45	5·027 340	530 072	140 230	896 880	860 642	130 935	882 92	456 63	15
50	065 835	576 379	197 028	968 234	953 022	255 304	11·059 43	726 74	10
55	104 902	623 442	254 859	7·041 048	8·047 565	383 066	241 71	14·007 86	5
60	144 554	671 282	313 752	115 370	144 346	514 365	430 05	300 67	0
Cot.	11°	10°	9°	8°	7°	6°	5°	4°	
Tan.	86°	Diff.	87°	Diff.	88°	Diff.	89°	Diff.	
0	14·300 67		19·081 14		28·636 25		57·289 96		60
5	605 92	305 25	627 30	546 16	29·882 30	1·246 05	62·499 15	5·209 19	55
10	924 42	318 50	20·205 55	578 25	31·241 58	1·359 28	68·750 09	6·250 94	50
15	15·257 05	332 63	818 83	613 28	32·730 26	1·488 68	76·390 01	7·639 92	45
20	604 78	347 73	21·470 40	651 57	34·367 77	1·637 51	85·939 79	9·549 78	40
25	968 67	363 89	22·163 98	693 58	36·177 60	1·809 83	98·217 94	12·278 2	35
30	16·349 86	381 19	903 77	739 79	38·188 46	2·010 86	114·588 7	16·370 8	30
35	749 61	399 75	23·694 54	790 77	40·435 84	2·247 38	137·507 5	22·918 8	25
40	17·169 34	419 73	24·541 76	847 22	42·964 08	2·528 24	171·885 4	34·377 9	20
45	610 56	441 22	25·451 70	909 94	45·829 35	2·865 27	229·181 7	57·296 3	15
50	18·074 98	464 42	26·431 60	979 90	49·103 88	3·274 53	343·773 7	114·592 0	10
55	564 47	489 49	27·489 85	1·058 25	52·882 11	3·778 23	687 548 9	343·775 2	5
60	19·081 14	516 67	28·636 25	1·146 40	57·289 96	4·407 85	Infinite	Infinite	0
′	3°	Diff.	2°	Diff.	1°	Diff.	0°	Diff.	′

Natural Cotangents

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